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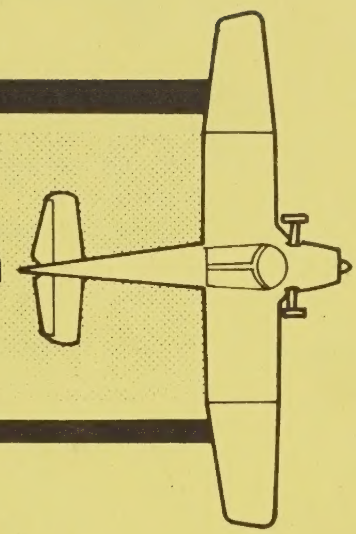
A PROBLEM ANALYSIS

Forest and Range Aerial Pesticide Application Technology



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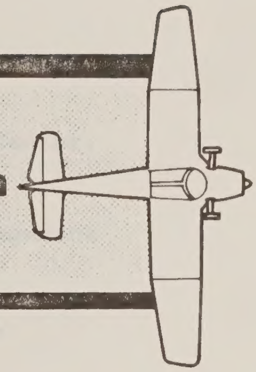

BY
Aerial Application Technology Workgroup

Robert Ekblad, *workgroup leader*
Jack Armstrong
John Barry
James Bergen
Imants Millers
Patrick Shea

Report produced by the Forest Service Missoula Equipment Development Center, Missoula, Mont.

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AUTHORS

Robert Ekblad, USDA Forest Service, Equipment Development Center, Missoula, Mont.

Jack Armstrong, Canadian Forestry Service, Forest Pest Management Institute, Sault Ste. Marie, Ontario.

John Barry, USDA Forest Service, Methods Application Group, Davis, Calif.

James Bergen, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

Imants Millers, USDA Forest Service, Northeastern Area State and Private Forestry, Portsmouth, N.H.

Patrick Shea, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Davis, Calif.

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Patrick Shea, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Davis, Calif.

ABSTRACT

This report identifies 10 general problem areas related to forest and rangeland aerial spray application: aircraft delivery systems; aircraft guidance; application strategy; biological interface; meteorology; pesticide safety; spray behavior; spray drift; spray sampling; technology transfer. These problem areas are divided into various problems and subproblems. Approaches to solutions are presented and specific actions to solve the problems are recommended. A discussion section weighs the importance of these 10 problem areas as each relates to reducing spray drift, reducing application costs, and improving spray control. Specific recommendations are included for implementing report findings.

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife — if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

Use Pesticides Safely
FOLLOW THE LABEL

CONTENTS

INTRODUCTION

Aerial application of pesticides is one of several tools available to the resource managers for insect, disease, and vegetative management on forest and rangelands. Techniques and equipment developed for aerial spraying of croplands have been adapted to aerial spraying of the forest--sometimes successfully and sometimes unsuccessfully. Forest spraying presents many problems not found in normal agricultural spraying: The target is a dense three-dimensional canopy; the terrain is usually irregular; both convective drainage and pressure gradient winds are common; aircraft cannot fly close to the crop; frequently high-quality water is nearby; there is difficulty in marking ground locations.

In January 1978 a Forest Service workgroup was appointed by the Chief of the Forest Service to prepare a problem analysis of forest and range aerial application. The workgroup was asked to accomplish three tasks:

- Review the state-of-art in aerial spraying.

- Develop a comprehensive document delineating forest and range aerial application problems and make recommendations to solve the problems.

- Determine the relative importance of these problems for groups funding or conducting aerial application research and development.

Although identifying biological problems was not a part of our charter, a majority of workgroup members felt it was necessary to include a section that considered the interface between engineering and biology.

Ten problem areas are identified and presented in the results section. Recommended approaches and specific actions for improving aerial application are given for each problem area. Priority for research and development in the 10 problem areas, along with the criteria used to set priorities, is included in the discussion.

A state-of-the-art summary for each problem area is presented in an appendix. Also included as appendix material is a general summary of current research and development in aerial application and a short historical overview of application technology pertinent to forest and range spraying.

APPROACH AND METHODS

Workgroup members were selected by the Chief of the Forest Service, and are the principal authors of this report. The workgroup included a mechanical engineer, a research meteorologist, two research entomologists, a field entomologist, and a pesticide application specialist. The group was sufficiently diverse to represent the points of view of each part of the organization, but did not represent every technical specialty. Other specialists, both in and out of the Forest Service were asked to contribute to certain sections of the report. Although the problem analysis was restricted to the U.S., one Canadian scientist agreed to serve as a workgroup member.

The memorandum authorizing the workgroup asked that the problem analysis should at a minimum:

• Highlight significant aerial application work in progress.

• Identify important problems.

• Subdivide these problems.

• Review the state-of-the-art in aerial application.

• Outline approaches to solutions.

• Identify specific actions needed.

These may be recognized as six of the nine elements specified under "Preparation of Problem Analyses," Forest Service Manual 4051.21e. Each of the elements has acquired a specific connotation. However, we chose to interpret problem analysis and its elements in a general sense. As a result, we replaced the word "studies" with "actions" to avoid the implication that each recommendation must result in a "researchable study." Actions may include preparation of manuals, training courses, monitoring of other agencies work, as well as research, development, and test.

The first workgroup meeting was devoted to defining problems. The division and grouping of problems was done for ease of analysis. The following 10 general problem areas were agreed upon and were used throughout the problem analysis:

• Aircraft Delivery Systems.

• Aircraft Guidance.

• Application Strategy.

• Biological Interface.

• Meteorology.

• Pesticide Safety.

• Spray Behavior.

• Spray Drift.

• Spray Sampling.

• Technology Transfer.

Each member was assigned one or more of these problem areas in which to review the state-of-the-art, determine subproblems, and recommend specific actions. Members were encouraged to seek assistance from other specialists. Subsequent workgroup meetings were devoted primarily to a review of members' writing on their assigned topics.

The results of the problem analysis are presented in the next section. Each problem area is presented separately and includes a statement of the problem and subproblems, suggested approach, and recommended action. The state-of-the-art review for each problem area is located in appendix A. Extensive literature citations were avoided intentionally in these reviews, which are dependent upon personal knowledge of the authors, reinforced by critical review of the workgroup.

A historical overview of both pesticide and herbicide aerial application was prepared and is included as appendix B. The report also includes a review of current research and development in aerial application sponsored by the U.S. and Canadian governments (appendix C).

RESULTS

AIRCRAFT DELIVERY SYSTEMS

Problem

The performance of individual components and total aircraft spray delivery systems has not been adequately quantified to permit development and selection of equipment and prediction of spray delivery in conjunction with a variety of spray materials, meterological conditions, and terrain.

Subproblems

1. We do not have an adequate description of the spray drop spectrum being emitted in the immediate vicinity of the nozzle for a variety of tank mixes.

2. We do not have adequate technology for establishing boom length, nozzle location, and both horizontal and vertical location of the boom.

3. Nozzles produce too many small droplets that are subject to drift, and at the same time produce large droplets that represent an immense overkill and waste pesticide.

4. We do not have adequate standards for selecting spray aircraft.

Approach to Solution

The common method for evaluating aircraft spray delivery systems has been to fly over a line of ground deposit cards. Swath widths, droplet distribution, uniformity of coverage, and mass recovery are then evaluated based on the droplet deposit on these smaplers. This technique integrates the effects of many variables: droplet spectrum, aircraft speed, local meteorology, evaporation, nozzle and boom configuration, and many others.

Recent advances in technology have made it possible to study the effects of many of these variables separately by using analytic and laboratory methods. By understanding the separate effects of these variables, significant advances should be possible.

Recommended Action

1. Develop analytic methods to predict spray particle trajectory based on the influence of gravity, aircraft wake, and wingtip vortices. Methods should be evaluated and adapted to forest spraying techniques and programed for solution on a computer.

Verification and refinement of the computer models would be done in two steps: Scale models of spray aircraft would be tested in the NASA vortex research facility. Further verification would be done with actual spray aircraft in a forest environment.

2. After the analytic analysis method has been verified, it should be applied to various spray aircraft to determine the effect of the following parameters on spray distribution:

- Configuration.
- Wing or disc loading.
- Airspeed.
- Altitude above target.
- Meteorology.
- Boom location and length.
- Nozzle location.
- Droplet spectrum.
- Evaporation.

With this technique, researchers would rely on the analytical and scale model test techniques for primary guidance in understanding the differences in spray delivery system performance. This understanding, combined with biological efficacy data (desired spray distribution), would permit decisions on the suitability of spray delivery systems for a given forestry mission.

3. Colorado State University is under contract to measure droplet spectrum emitted at the nozzle in a controlled wind tunnel. The University of New Brunswick is doing similar work. The methods should continue to be evaluated and standardized for additional nozzles, aircraft speeds, and tank mixes.

4. The National Aeronautics and Space Administration (NASA) is sponsoring studies that may lead to a nozzle producing more uniform size droplets. Various manufacturers are developing nozzles they claim will reduce the number of small droplets. This work should be closely monitored and encouraged. If a new nozzle appears promising, it should be tested in the wind tunnel.

5. Swath widths and distributions measured at ground level are distorted due to the vortices moving outward as they approach the ground. Techniques to measure the effective swath width and uniformity of the coverage at canopy top should be devised. This can probably be done in conjunction with action 1.

6. The Forest Service Missoula Equipment Development Center (MEDC) has a contract with Colorado State University to measure change in droplet size with time due to evaporation. These tests should be expanded to include other tank mixes and the effect of additives. As data become available, the empirical results should be analyzed to determine if simpler tests or analytic methods can approximate evaporation.

7. Ground-based piloted flight simulators with programed terrain models are available from industry and other government agencies. These should be investigated to determine if they are suitable for measuring horizontal and vertical tracking ability of various spray aircraft.

8. A simple method for comparing spray efficiency has been developed jointly by MEDC and Forest Insect and Disease Management/Methods Application Group (FIDM/MAG). This Deliverable Dose Index (DDI) Method is based on counting droplets of the required dosage that can be delivered to the target. A computer program is available to compute DDI. The program should be further evaluated and modified to include evaporation.

9. Several computer programs are available to predict aircraft productivity for various classes of aircraft and types of spray missions. The programs should be reviewed and the best one adapted to predicting costs and productivity for Forest Service spray missions.

10. Many different additives are available that alter the physical properties of pesticide tank mix, and in turn alter the spray droplet spectrum and the spray droplet evaporation rate. A study should review and evaluate additives to better control evaporation, production of fine droplets, and physical parameters. This would not include additives used primarily to modify toxicological properties.

AIRCRAFT GUIDANCE

Problem

Present guidance systems are inadequate to insure even application and deposition of aerially applied pesticides over complex forested lands. The marking techniques are costly and of limited value in maintaining even swathing, delineating boundaries, relocating unfinished swaths, and locating treatment areas. Maintenance of even swaths over forested lands is critical to the efficient and effective application of pesticides.

Approach to Solution

Because several electronic systems are available, it would seem feasible to design several experiments to first demonstrate their utility. Assuming satisfactory results, a rigid experimental program could be embarked upon to test the best systems against existing methodology. Further, assuming the various new systems are superior to existing methods, an additional experimental program would be initiated to compare the effectiveness of specific systems. A progressive series of situations, ranging from airport tests to actual field tests, would be necessary to gather data on suitability, accuracy, and cost effectiveness before the system(s) could be released for pilot tests or operational programs.

Studies should concentrate on learning the capabilities and limits of these systems to better assess the systems available from Forest Service contractors.

Recommended Action

1. Test Loran C., Motorola Mini Ranger, Omega GNS, and Del Norte Electronic positioning systems for maintenance of parallel swaths, evenness of deposition, width of effective swaths, ability to relocate unfinished swaths, guidance of pilot to spray boundaries, etc. Tests should be conducted over flat terrain, such as an airport, using appropriate statistical design and analysis and a land-based tracking system, like theodolite or radar.

2. Same as (1) except that the test would be conducted in mountainous terrain with plots of about 100 acres. Add existing methodology like banners or flags as experimental variables. Test for parallel swathing, deposition, location of blocks, location of unfinished swaths, and swath width.

3. Same as (2) but the complexity of the test should be increased by increasing the size of blocks.

4. Assuming positive results from the previous tests, begin development of additional computer software to provide parallel contour operation.

5. Investigate adding equipment to electronic guidance systems to plot swath paths on a map located on the ground.

APPLICATION STRATEGY

Problem

We do not have a framework to organize information and to develop a strategy for planning and conducting aerial spray projects.

Subproblems

1. The kinds of information necessary to specify application procedures have not been fully described. The degree of precision of the knowledge should be specified.

2. Useful procedures developed for and by many field practitioners have not been identified, reviewed, evaluated, and made widely available.

3. A model is needed that uses, as input, all fixed and variable parameters associated with aerial application and produces as output a prescription for spraying a particular target.

Approach to Solution

Strengthening Forest Service capability to plan, conduct, and evaluate aerial application projects is envisioned to take 5 years to complete if given adequate priority. To accomplish this will demand a considerable technology transfer effort. This will include identifying existing data, information, and technology, and putting these into user form for field use. Concurrently, work would commence to develop a systems approach to the problem to include use of mathematical models as decisionmaking tools in developing spray strategy.

Recommended Action

1. Publish a reference manual for project directors for planning and conducting spray projects. This would include information currently scattered among books, pamphlets, reports, and articles. This would get the information into the user's hands while the systems and modeling approaches get underway.

2. Develop a framework for a systems approach to application. This effort would establish the step-by-step tasks to accomplish a decisionmaking process for the resource manager and project director to select spray equipment and spray methods, and to achieve desired results within geographic and socioeconomic constraints.

3. Synthesize a mathematical model to predict the air concentration and deposition of particles on targets as functions of the spray equipment and techniques for application, atomization, weather, topography, forest, target, etc.

4. Extend the work of (3) by including target's biological response in the model to permit predictions of mortality as a function of:

- Application techniques and equipment.
- Atomization.
- Weather.
- Topography.
- Forest and tree characteristics.
- Physical aspects of the insect.
- Economics.

5. Publish a spray application manual incorporating all data and information the project director needs for proper planning, efficient execution, and complete evaluation of aerial application projects. This manual would be an updated version of the one described in (1), and incorporating all that was learned in (2) and (3).

BIOLOGICAL AND AERIAL APPLICATION TECHNOLOGY INTERFACE

Problem

A lack of information on the relationship and interaction of the pesticide, environment, weather, and host to the target pest has resulted in pesticide field experiments, pilot projects, and operational projects with highly variable results. This phenomenon is particularly true with biological agents. Advances in aerial application technology are hindered by this lack of information.

Approach to Solution

The basic approach to this problem involves: (1) collecting information; (2) defining specific problems; (3) conducting a series of laboratory and field studies and experiments over 3 to 5 years to obtain quantitative information for predictive modeling systems. These systems will be used to prescribe a treatment and to predict probability of success or failure of a given spray strategy.

In planning and conducting aerial spray projects, it is essential for the development of spray strategy, selection of spray equipment, selection of a pesticide, and timing of spray application that we understand the interactions among the pesticide, the target organism, and its environment.

The biologist must tell the engineer how the pesticide must be presented to the insect. This includes timing of application, number and size of drops, atmospheric conditions, nature of the target population, method of contact, etc. With this information, the engineer and applicator can develop the most economic and efficient method to deal with the pest. Deriving the prescription would be based on a system's approach through a spray model. The model would serve to organize, evaluate, and weigh the biological information.

Recommended Action

1. Collect information on biolcgical interface by insect; organize and publish this information in a source book.

2. Assemble information on biomass to include distribution of coniferous and deciduous foliage in the vertical and horizontal plane, leaf measurements, and leaf number per unit area for each forest type and species composition where pesticides may be deployed. Some of this information exists, however, it will involve an effort to assemble it in a usable form.

3. Adapt or develop a system to categorize forests in terms of height, crown, stem density, and foliage density so a field technician can categorize a spray block.

4. Study and characterize the physical properties of the leaf as they relate to spray droplet retention, reflection, bounce, spreading, and absorption. This should be done by an investigator with high speed photography and measurement techniques such as lasers.

5. Collect and publish data on weight and dimensions of all economically important forest defoliators by instar.

6. Determine effects of temperature and photoperiod on forest defoliation by instar as they affect the larva position and behavior on the host; and as they affect the vulnerability of the larvae to pes-

ticides. This would be done with each major forest defoliator and with at least four chemical and biological pesticides. Determine if wind, sunlight, barometric pressure, precipitation, and relative humidity should also be studied.

7. Continue studies to determine susceptibility of insect populations to direct control with pesticides as a function of population dynamics, genetics, age of infestation, and health and condition of population.

8. Determine optimum spray droplet size and range and their relationship to number of droplets, and toxic concentration of droplet to efficacy. This would be done in the field on a natural population.

9. Determine the methods of how the pesticide reaches the target and what percent of mortality is a result of inhalation, ingestion, direct contact, or delayed contact. Identify any special mode of action or mechanisms associated with transferring pesticide from the contact surface to the insect.

10. Determine for selected pesticides the single droplet size that contains a lethal dose and publish data in a suitable reference publication.

11. Determine significance and amount of active ingredient lost from spray droplet during both atomization and transport to the target.

12. As an extension of these substudies, develop a prescription to apply pesticides to forest defoliators by instar for inclusion in application models.

METEOROLOGY

Problem

Present threshold requirements for aerial application have not been adequately defined, nor can they be related to either synoptic scale climatology and forecasts or onsite measurements in nonuniform terrain.

Subproblems

1. Accurate models of spray behavior require input on wind velocities and mixing efficiency that are difficult to measure onsite.

2. Weather criteria for spray operations do not avoid long and medium-range drift hazard.

3. There is no general way of estimating the morning wind field or the temperature inversion pattern on the 1 to 20 kilometer scale.

4. Onsite meteorological measurements are not comprehensive enough to estimate drift hazard or spray behavior. In forested areas and in complex terrain they may not be representative of the spray environment.

Subproblem 1

Accurate models of spray behavior require input on wind velocities and mixing efficiency that are difficult to measure onsite.

Background

Both the tilted plume models and more sophisticated calculations of spray behavior require some estimate of the efficiency of vertical turbulent mixing in the height region containing the material. While the plume models operate on single, average values of this efficiency as well as windspeed, other more accurate approaches will require vertical profiles of these variables.

For range vegetation and moderate temperature changes with height near the surface, the wind velocity profile and the turbulent mixing coefficient profile can be estimated from the speed at one level, the roughness at the surface, and some indexes of the surface energy balance such as cloud cover, Bowen ratio, etc.

For hilly or mountainous terrain, the profiles assume more complex shapes particularly in the downslope wind often called "cold-air drainage."

Profile estimates above forests cannot be made in any simple manner even for level stands if the temperature change above the canopy exceeds particular values determined by the windspeed profile (as described by the Richardson Number). Situations for forest covered slopes with "cold-air drainage" winds are mostly unexplored.

The bulk of forest spray applications involve stands in the 15 to 35 m height range. The droplets or particles spend a major fraction of their trajectory below the treetops where wind velocity and turbulence depend on the forest canopy structure, that is "canopy flow."

Aside from the first situation mentioned, onsite profile measurements of wind velocity and turbulence in these environments present difficulties for field conditions. There is too much point-to-point variation for downslope and canopy flow, while the problem of getting profile equipment above typical forest stands rules out such measurements above even level forest sites.

Approach to Solution

The problem of estimating mixing efficiency over level forest stands with a strong decrease of air temperature above the tree crowns (a high Richardson Number), as is common during spray operations, can be approached in a semi-empirical way if the energy changes involved in the loss or gain of water vapor by the foliage can be neglected. This could be reasonable with very low levels of illumination. The shape of the wind velocity profile and the mixing efficiency should then depend directly on the crown dimensions, the crown closure, windspeed, and some index of the radiation loss from the crowns; for example, cloud cover, relative humidity, and air temperature at some surface station.

The problems involved in canopy flow speed estimates are somewhat less tractable and involve some basic questions that also arise in droplet interception problems--the size and shape of the wakes around branches and needles, and the interaction of these wakes with other air motions produced by the tree crowns.

Cold-air flow over reasonable extensive slopes, away from ridges and deep gullies and over bare or brushy slopes, has been shown to have a well-defined velocity profile that depends largely on the radiation lost by the slope, the insulating properties of the surface, and the slope grade. While virtually no measurements of turbulent mixing have been made in such winds, theory suggests that the mixing efficiency should depend on the surface roughness and these same variables.

Cold-air flow in forest canopies involves the thermal radiation balance in the canopy. A potentially useful analysis has been made for mixed spruce-fir on hillsides, but generalization of these results to other stand types awaits a working solution of the problems described above.

Recommended Action

The specific actions can be divided into two general regimes: The local or microscale and the large area or mesoscale.

Microscale research problems:

1. Assemble wind profile and turbulence data available and put together an approximate typology shape of the wind profile as it relates to foliage distribution.

2. Execute numerical experiments with models of canopy airflow and turbulence to be compared with existing data from conifer stands.

3. Carry out wind tunnel study of conifer branch wakes and drag forces at very low airspeeds.

Mesoscale research problems:

1. Refine nocturnal valley and crossridge flow models and other topographic flow models in various topographic and synoptic situations.

2. Model sideslope flows and their interactions with canopy cover as a drag element and heat sink.

3. Combine valley flow and sideslope models to predict mixing and dispersion of the sidehill flows into the main valley flows.

Subproblem 2

Current weather criteria used on operational spray operations do not avoid long- and medium-range drift hazard.

Background

Current Forest Service Manual guidelines advise against aerial applications when windspeeds exceed 6 mph, when air temperatures exceed some specified threshold, and if relative humidities fall below some threshold value. Maximum downwind distances to sensitive areas are not specified except implicitly in terms of an effective swath width.

Both past experience and current atmospheric transport model predications indicate that such guidelines cannot guard against appreciable contamination of areas well downwind of the target region.

Even in very level terrain, the movement of pesticides varies with surface heating or cooling, the roughness of the surface, and the local temperature inversion height, in addition to droplet or particle size and release height.

In mountainous terrain all weather variables may vary sharply both along the flight path and between the flight path and sensitive areas.

The state-of-the-art in predicting atmospheric transport in level terrain allows relatively accurate estimates of drift hazard, however defined, for applications over level surfaces with grassy or low shrub cover typical of rangeland. In high vegetation like forests, uncertainties about the retention of materials diffusing to the surface arise that make it more difficult to estimate upper and lower bounds for concentrations and deposition at various downwind distances.

For mountainous areas, where local wind and inversion patterns must be estimated indirectly as a practical matter, the interval of uncertainty becomes large with current models.

All feasible models for transport and mountain wind and temperature estimates require local weather measurements. The number of such measurements generally increase with the complexity of the terrain. With forests, additional difficulties arise in obtaining measurements not dominated by local irregularities in the forest cover. This problem is particularly severe in the early morning.

Approach to Solution

Forest Service policy places primary emphasis on avoiding public health hazards or environmental damage; efforts to increase efficacy of control and cost efficiency must be secondary. The first goal of the meteorological effort should be to establish dependable (not estimated) upper bounds on the drift hazard.

An analysis of transport models indicates that the tilted plume models without depletion are generally "conservative" in regard to local airborne concentration. That is, the errors all tend to overestimate local concentration at any downwind distance. Such models would obviously underestimate deposition at a particular location. But upper limits for such deposition can be generally established from local windspeed, surface roughness, and the droplet or particle size.

For volatile materials, the plume calculations must include enhancement or source terms reflecting the measurement of a droplet from one size range to the next as vapor is removed; and one plume must represent the vapor phase of the material. Such a set of calculations poses no theoretical problems, but would require a computer program.

The basic tilted plume model has been extensively developed for military purposes, tested in a variety of rangeland situations, and is available, with full documentation and user's guide, as a computer program from the Department of Defense. The program has been successfully operated at the Fort Collins Computer Center and at Berkeley.

Weather input to the model can be reasonably reduced to an estimate of the height, cloud cover, average windspeed below the release height, and the surface roughness.

The current model does not include evaporation effects, but these can be incorporated by repetition of the calculation.

The plume model should be directly applicable to rangeland application, in as far as the delineation of "safe" release zones is possible for a wide variety of application estimates and weather conditions.

The TP (tilted plume) model has been matched with the shallow fluid mountain wind prediction model of Tingle and Bjerklund and others in a program called EPAMS, which is available from the same agency. The plume model calculation is essentially repeated at specified intervals along the calculated path of the air layer below the inversion.

Weather input to the model, estimates of inversion heights, and strength and windspeeds over the upwind boundary of the region of calculation is the same as for the TP model. Other input consists of topographic map data.

In a broad sense, the SF (shallow fluid) model is also conservative. By allowing the surface inversion to vary over the area of calculation, higher concentrations of materials are predicted in valley bottoms and canyons typical of stream courses and populated areas than would be the case for a more realistic model or rigid lid model.

No discontinuity of the inversion is allowed. There is no loss of material to the atmosphere above the inversion, a feature that would almost always result in local overestimates.

Because of these and other details, EPAMS can best be described as a relatively inaccurate but conservative (overestimation) drift hazard model that should be easily adaptable to Forest Service requirements in mountainous terrain for protecting sensitive areas.

It should be emphasized that neither model is very accurate. They represent only a starting point. More reasonable representation of the physical processes, particularly the energy exchanges at the terrain surface, at the inversion level, as well as surface friction, will result in smaller "buffer zones" and estimates of optimism spray strategies via canopy flow and spray behavior models. But the direction of progress will be in accordance with the priorities above.

Recommended Action

1. Review of existing field data appropriate to lists of SF model or EPAMS.

2. Conduct field tests with tracers of EPAMS buffer zone predictions.

3. Incorporation of an evaporation routine into TP model and EPAMS.

4 Recoding of EPAMS for Fort Collins computer and redrafting of documentation for line organization use.

5. Incorporation of Forest Service inventory data into the default modes of TP and EPAMS.

6. Climatological evaluation of buffer zones calculated by EPAMS with a study of timber management implementations.

7. Dissemination of TP documentation for Forest Service use.

8. Onsite monitoring design.

Subproblem 3

There is currently no general way of estimating the morning wind field and the temperature inversion pattern on the 1 to 20 kilometer scale.

Background

Realistic estimates of the atmospheric transport patterns, in contrast to the upper bound estimates, and acceptable inputs to spray behavior models require formulations of the thermodynamics and turbulence properties of the surface layers of the atmosphere.

Currently, such formulations pose problems of computer capacity and expense when introduced into numerical boundary layer and terrain effects models. Recent progress in computer designs indicates that such considerations will become much less constraining.

Improvements in predicting accuracy can be expected with the introduction of:

1. Energy balance equations, including radiation and heat release from dew or frost formation or evapotranspiration.

2. Turbulence models, including transport.

3. Inversion formations and dissipation in the region of computation.

4. Interaction of tall canopies with the inversion flow.

Approach to Solution

Boundary layer models oriented toward complex terrain are emerging as a result of concern from agencies such as EPA, DOE, and DOD with pollution of undeveloped areas. Most of these studies show very little interaction with field observations of small-scale climate in such areas. Such confrontation and feedback probably are most appropriate for Forest Service capabilities.

Recommended Action

1. Liaison committees with agencies having major research efforts in this area. Examples are the Atmospheric Sciences Laboratory at Whitesands, N. Mex., Atmospheric Turbulence and Diffusion Laboratory at Oakridge, Tenn., and NCAR.

2. Cooperation studies with these agencies on short-time tests or experiments.

3. Small-scale experiments by Forest Service scientists on critical assumptions or problems encountered in the adaptation of such models to areas of Forest Service concern; for example, inversion physics on the microscale.

Subproblem 4

Current onsite meteorological measurements are not comprehensive enough to estimate drift hazard or spray behavior. In forested areas and in complex terrain they may not be representative of the spray environment.

Background

Onsite measurements in spray operations generally have been limited to windspeed and direction, air temperature, and relative humidity measured a few feet above the ground that may not be representative of the spray block. In forested situations they have often been made in roads or clearings that may not be representative of the spray block.

When such measurements are taken as directly representative of conditions between the effective surface of deposition and the height of release, they may result in serious errors in estimates of swath orientation and extension. Evaporation would tend to be underestimated. They do no furnish information on the presence or location of temperature inversions.

When such measurements are made in forest roads or clearings with cross-wind dimensions comparable to

tree height, windspeed and direction may be completely uncorrelated with conditions over the canopy.

Approach to Solution

Measurements needed have frequently been made with tethered balloons. For open sites, this is a practical method, for temperature and wind conditions can often be estimated from tether angle, the balloon lift, and the estimated drag coefficient.

For sites with heavy forest canopy cover, balloons may be impractical. A possible alternative that does not seem to have been tried is the acoustic sounder, which utilizes the reflection of sound by regions at sharp air temperature changes at an inversion, the acoustic radar. A burst of sound is emitted by a relatively compact speaker and the resulting echo is detected by a microphone. The time between the end of the sound pulse and the end of the echo is translated into an effective height shown by a darkening on recorder paper on a height versus time display. The amount of darkening corresponds to the intensity of the echo that corresponds to the intensity of the inversion if allowance is made for varying distances.

A less common adaptation is the bistatic sounder, using two microphones where the windspeed near the level of the echo may be inferred from the frequency shift of the echo between the two microphones.

Such equipment may be used beneath canopies by adjusting the time interval between the end of a pulse of sound and the activities of the microphones to exclude canopy echos.

This equipment can be battery operated and very compact in still environments.

The use of smoke is relatively common place, either released from the air or from the ground by a commercially available cartridge-powered gun. Such measurements are, however, extremely difficult to interpret in terms of average wind conditions.

While all three types of measurements have promise, the acoustic techniques offer the advantages of convenience and relative comprehensiveness. The inversion height, the inversion intensity, and the windspeed near the inversion can be interpreted directly as input into drift models such as the EPAMS or TP. The equipment is durable and relatively inexpensive, and could be adapted to remote monitoring.

Recommended Action

1. An evaluation of acoustic ranging techniques for spray weather surveillance from available data. Results would include conclusions on the merit of available equipment and the possibility of modification.

2. Field tests of bistatic acoustic sounders with comparison with teathered balloon data.

A variety of terrain situations and forest cover would be used.

PESTICIDE SAFETY

Problem

Procedures and methods for insuring personnel protection are not standardized and are not given sufficient emphasis on pilot and operational spray projects.

Approach to Solution

Problems discussed in the state-of-the-art section cover the following four major areas: project management, personnel training, protective clothing and equipment, and standardization of procedures.

Recognizing that administrative guidelines, methods, and equipment for protecting personnel from exposure to toxic pesticides exist, the problem is simply one of technology transfer and establishing minimum procedures for the field.

The approach is simple and straight forward. A safety manual dealing with protecting personnel from field application of pesticides should be published. In addition to specifying protection procedures, it would standardize procedures throughout the Forest Service.

Following publication, training should be given to all Forest Service personnel and cooperators who deal administratively or operationally with pesticide application.

Recommended Action

1. A safety manual should be prepared for field use specifying methods and procedures for protecting personnel from pesticides on aerial spray projects during mixing, storing, handling, and application.

2. Pesticide safety training should be given to managers and personnel involved with pesticide spray projects. Training would emphasize implementing Forest Service Manual (FSM) guidelines and procedures that specify how to conduct safe aerial spray projects and provide personnel protection. Clothing and equipment needed to protect field personnel should be specified for each pesticide in use by the Forest Service.

3. Organization and format of project safety plans should be standardized.

SPRAY BEHAVIOR

Problem

Quantitative data on the physical behavior of spray droplets are needed from the time the spray leaves the aircraft spray system to the time it comes to rest or is changed from a liquid to a gaseous state. A systematic engineering approach using computer modeling techniques is needed to make full use of all information and data on spray behavior. The overall model would balance and weigh each input and provide the planner with options and alternatives for decisions. Output could be used during all project phases, including planning, spraying, and evaluation.

Approach to Solution

A combination of analytic studies, wind tunnel tests, and field tests will be needed to adequately address this problem.

The physical behavior of spray droplets can be divided into four regimes:

1. Droplet formation and shear effects near the nozzle.

2. Interaction of droplets and aircraft wake.

3. Atmospheric and gravitational effects on the spray cloud above and through the vegetative canopy.

4. Capture and retention of spray droplets at the target.

The first two regimes have been addressed in the aircraft delivery system section of this report and will not be pursued, because the behavior in the first two regimes is influenced primarily by the spray system and aircraft and should be studied by an aerodynamicist. After stabilization of the spray cloud, the behavior is governed by atmospheric effects and vegetative cover. These topics are properly studied by meteorologists and atmospheric physics.

The application of an aerial spray is governed by the desire to maximize the deposition of the pesticide on the target area and to simultaneously minimize adverse environmental impacts that may be caused by the spray. Consequently, the analysis of spray behavior has concentrated on two problem areas. One is concerned with obtaining techniques for optimizing the deposition of the spray and the other is concerned with developing methods for minimizing environmental impacts. These problem areas are

usually called the deposition problem and the drift problem, respectively. Ideally, the complete resolution of each problem requires a knowledge of the temporal and spatial variation of the size and concentration of each droplet comprising the spray.

The Forest Service has funded research and development for several years in the area of spray behavior with considerable progress. Extensive studies and techniques have been developed for air pollution and military applications. An immediate study should be undertaken by an independent group to establish the best framework for further development, taking into account current state of development and validation, ease of adding additional parameters, cost and simplicity of use, and overall cost.

Recommended Action

1. A study should be conducted to select the best theoretical model or models for predicting both spray deposition and spray drift.

2. A study is in progress to determine evaporation rate of several pesticide tank mixes. Upon completion of the contract, this information must be incorporated in the spray behavior models.

3. Continue development of spray behavior models and incorporate information as it becomes available.

4. Conduct laboratory and field tests to validate models and establish limits of accuracy.

5. Conduct laboratory and wind tunnel tests to develop recommendations for use of adjuvants to reduce evaporation.

SPRAY DRIFT

Problem

Pesticide drift into sensitive nontarget areas has the potential of causing environmental contamination, public health hazards, adverse publicity, and increased project costs from claims and legal actions.

Subproblems

1. All available technology is not being applied to reduce or eliminate pesticide drift outside target area.

2. Lack of monitoring drift outside of spray areas may have caused unwarranted claims and has prevented accumulation of historic data.

3. Project managers are not aware of available technology to reduce nontarget drift.

4. Usually, minimum acceptable drift standards are not established to allow for low-cost monitoring.

Approach to Solution

Aerial drift caused by the normal application of pesticides cannot be eliminated. However, the drift can be managed to reduce serious problems.

Aerial application of pesticides, including drift management, involves highly technical skills not learned in normal forest management. Some of these skills needed for drift management include knowledge about spray cloud behavior and interpretation of meteorological conditions. Previous experience on spray projects should be required of all project supervisors. Certification as a result of previous experience, training or testing provides administration with some idea of what accomplishments may be expected.

Most project personnel are not involved in continuous aerial application activities and therefore need reference materials to refresh their memories and to catch up with new developments. Manuals, guidelines, workshops, and selected work-plans may suffice.

Elimination of all drift is not realistic. Standards are needed to

set limits for the project supervisors. Specified standards will allow development of simplified equipment and methods to determine if standards were met.

Present low-volume insecticide rates do not permit continuous observation of the cloud to determine if spray is reaching the target areas. Smoke or dust markers need to be developed to detect poor application conditions or the need for flight adjustments near sensitive areas.

Contradictory statements in the scientific literature confuse administrative and aerial project management. Droplet size range should be determined to achieve the most effective, economic, and safe application for each pesticide.

Recommended Action

1. Develop a training program for drift management and establish training requirements for all project supervisors.

2. Develop manuals, guidelines, and other reference material with continuous updating to incorporate new developments.

3. Establish minimum standards for pesticide drift for each pesticide.

4. Test or develop simplified, inexpensive equipment and methods to monitor spray drift.

5. Smoke or dust markers need to be developed for operational use to detect poor application conditions or the need for flight adjustments near sensitive areas.

SPRAY SAMPLING

Problem

The Forest Service has not adapted existing methods and techniques of sampling pesticide sprays to obtain data for its own needs and those of regulatory agencies.

Subproblems

1. Levels of detection of pesticides must be specified by agencies having legal responsibility.

2. Improved methods are needed to sample deposition quantitatively of both dyed and undyed sprays on the ground and in trees.

3. Collection efficiency and performance data are needed for each sampler used to sample pesticide sprays in forests.

4. A method is needed to determine spread factors of pesticide droplets on deposit cards and paper at time of application.

5. Samplers should be indentified and evaluated for quantifying air concentration of insecticide within and downwind of spray areas.

6. Standards should be developed for sampling sprays on pilot and operational control projects to include a sampling plan specifying types, number, and positioning of samplers, levels of detection, and precision.

7. Sampling methods are needed to obtain correlations between spray deposit and insect mortality.

Recommended Action

1. Washington Office Forest Insect and Disease Management Staff should specify off-target levels of detection needed for spray deposition and air concentration sampling of pesticide sprays based upon State and Federal laws and guidelines. Specifications should be stated officially and sent to Regions and Areas.

2. Conduct a series of field trials in both deciduous and coniferous forests to select or develop a sampling technique or method to obtain spray deposit data on size and number of spray droplets deposited in trees. Techniques are needed for both dyed and undyed pesticide sprays.

3. Determine collection efficiency and performance of deposition and air concentration samplers used by the Forest Service to sample pesticide sprays. This would involve both water and oil-base sprays and volume median diameters ranging from 110 to 1000 μm.

4. Conduct a series of field trials to develop and evaluate a simple field method of determining spread factors for each application onsite. Spread factors so determined would be used to analyze the spray deposit data for that application.

5. Identify equipment suitable for sampling air concentration of pesticides inside and outside spray areas. Study should include cost and operating procedures.

6. Develop a field manual covering all aspects of spray sampling on pilot and operational projects.

Sampling methods are needed to obtain correlations between spray deposit and insect mortality.

7. Identify, develop, and evaluate a standard method of sampling spray deposit in both deciduous and coniferous forests to obtain correlations between deposit and insect mortality.

TECHNOLOGY TRANSFER

Problem

Existing technology is not being used to the extent possible to improve the planning and conducting of operational spray projects.

Subproblem 1

Project supervisors are not prepared to deal with the complexities of aerial application projects. Minimum requirements are not set for project managers. Lack of training, experience, and inadequate project planning results in poorly executed projects.

Subproblem 2

Reference materials needed for training, planning, and administration of aerial spray projects are not easily available to the project supervisors in the field. Information is scattered in highly technical publications, administrative guidelines, and administrative directives. Technical information is buried in private and quasi-published reports and is not available for use in the field. This information includes experiences and critiques of completed aerial application projects.

Subproblem 3

Research and development pertaining to aerial application technology is reported in journals and periodicals encompassing many disciplines. As a result, very few people are aware of the latest methods and equipment in aerial application technology. None of the library or information services available have comprehensive coverage of this topic.

Approach to Solution

Solution to this problem can be divided in three areas: collecting and documenting available information; training; and providing continual updating of information.

The need for technology transfer is not limited to exchanges between researchers and users. Aerial application and research and development are carried on in several countries and involve many disciplines that report in journals of their own specialty. Technology transfer is needed at all levels and should be international as well as interdisciplinary.

Preparation of manuals and handbooks is notoriously slow, and they need continual updating. Therefore, they must be supplemented by periodic training and continual feedback from users.

No individual can be expected to locate, much less read, all the information being reported on aerial application technology and other fields useful in aerial application, such as pollution control. Many reports are in proceedings or other limited-circulation reports that rarely appear in common abstract lists. The individuals involved in aerial application represent several scientific disciplines and have a variety of personal contacts. If each individual would submit information on publications, new projects, meetings, workshops, and new products to a central group that would, in turn, publish an informal newsletter, communications would be greatly improved.

Recommended Action

1. Provide training sessions and opportunities for prospective project supervisors to participate on spray projects to increase knowledge for project supervisors and their staffs. To assure the forest managers that their projects have adequate technical guidance, a form of certification may be necessary. Certification of managers will increase their authority and help reduce administrative interference.

2. Develop aerial application handbook, reference bibliography and a list of experts for consultation. This will assist project supervisors in planning, organizing, and executing aerial spray projects.

3. Institute an informal publication devoted to aerial application technology for forest and range. The publication should contain an abstract of recent publications and brief, contributed articles. The writing should exclude biological, chemical, and engineering technical jargon to appeal to a wide audience. "Reforestation Notes" published by the Forest Service Pacific Northwest Region, Division of State and Private Forestry is a good example of such a publication (appendix D).

DISCUSSION

In general, the workgroup has confidence that the appropriate problems and actions have been defined. Shortcomings are likely to be subproblems that we have overlooked rather than inclusion of trivial problems.

The workgroup did not attempt to estimate costs for various actions. Costs will vary, depending on what organization does the work, the sophistication of the approach, the timeframe for completion, and the scope of the work.

Three criteria were established for setting priorities for the 10 general problem areas:

1. Drift reduction.

2. Reduction of application costs.

3. Improved effectiveness of control.

Based on these criteria, the workgroup set the priorities for the 10 general problem areas.

Problem Area	Priority[1/]	Expected Contribution to Drift Reduction	Cost Reduction	Increased Efficacy
Aircraft Delivery Systems	9	High	High	High
Aircraft Guidance	7	High	Low	High
Application Strategy	6	Medium	Low	High
Biological Interface	4	Low	Low	High
Meteorology	6	High	Low	Medium
Pesticide Safety	3	Low	Low	Low
Spray Behavior	8	High	Medium	High
Spray Drift	5	High	Low	Low
Sampling	3	Low	Low	Low
Technology Transfer	9	High	High	High

1/ Priority on scale from 1 to 10; 10 highest, 1 lowest.

Initially the workgroup had intended to establish more detailed priorities for research, development, test, and administrative actions. It appears that setting priorities and establishing schedules for solutions must go beyond purely technical considerations and include policy decisions about objectives of sponsoring group, allocation of resources, degree of risk acceptance, and priorities between short-term and long-term goals. It was, therefore, decided not to set detailed priorities, but recommend that a new group, including some members of the present workgroup, be selected to establish detailed priorities and schedules.

Many of the actions recommended are already underway at one or more facilities.

Additional background for each problem area is given in the state-of-the-art section (appendix A). A review of that section may be necessary to understand the rationale for some of the proposed actions. The state-of-the-art was judged to be too voluminous to include in the results.

Due to the complexity of the subject matter a short background statement has been included with each subproblem on meteorology. The meteorology state-of-the-art section is highly technical and has been included for review by specialists in that field.

Considerable time was spent reviewing problems associated with herbicides, including interviewing herbicide specialists. The problems in aerial application technology associated with control of vegetation did not appear to be sufficiently unique to warrant a separate section. However, when considering proposed actions in evaporation, drift, nozzle testing, etc., the equipment and materials should include both insecticides and herbicides. The most significant finding about herbicide application technology is that very little research and development is being done by the Forest Service. Therefore, the technology transfer problem from chemical companies, universities, and other agencies doing research and development is important.

RECOMMENDATIONS

1. Adopt this problem analysis as a framework for future Forest Service research and development in aerial pesticide application technology.

2. Establish an ad hoc committee to provide a detailed planning document to implement the results of this problem analysis. The committee should include one or more of the original workgroup members, but should be composed primarily of individuals who are in policymaking positions. They could utilize technical specialists to perform staff work for them.

3. Reconvene the aerial application technology workgroup annually to update problem analysis and review the past year's accomplishments. Membership in the workgroup could be rotated to include new members and still retain continuity.

During the course of the problem analysis the state-of-the-art relating to each problem area was reviewed. The following section contains these reviews.

The material was judged to be too voluminous to the main point, the proposed actions, to be included in the main body of the report.

The rationale in selecting the problem areas and proposed actions will be more clear after reading the state-of-the-art reviews.

The review of meteorology is highly technical and is intended for a technical specialist rather than the general reader.

AIRCRAFT DELIVERY SYSTEMS

AIRCRAFT

Selection of spray aircraft is usually dictated by availability and cost. After World War II, military aircraft were adapted to fire retardant bombing and smokejumping. The same aircraft were used for aerial spraying of forests. As piston engine helicopters became available, they were used because of their increased maneuverability, short ferry distance, and slow speed with increased downwash. As turbine helicopters were introduced they were accepted for spray use even though their flight characteristics are significantly different than piston helicopters. Large fixed-wing aircraft, obsolete for commercial transportation, were introduced into Canada because of the large acreages and the gentle, rolling terrain. The advent of turbine, single-engine Ag aircraft caused new interest in fixed-wing aircraft for the mountainous West.

The spraying period is of short duration and intermittent, so the spray plane is usually adapted from aircraft that are available from fleets for other purposes. The introduction of new spray aircraft is usually initiated by spraying contractors since primary bid requirements are based on dollars per acre and minimum daily productivity. Occasionally, fixed-wing or rotary-wing aircraft are specified. The Forest Service Aviation and Fire Management Staff determines if the aircraft has sufficient power, payload, and safety for spraying. This is usually based upon fire-related aircraft performance.

With the exception of single engine Ag aircraft, very few aircraft are fitted out exclusively for spraying. Most have easily removable systems that leave the aircraft useful for other purposes. Very little numerical evaluation of various aircraft for performance in delivering spray has been done. This will be discussed further in the spraying system section.

SPRAY SYSTEMS

The most complex component of a spray system is the nozzle or atomizer. Atomizers are widely used for other applications. Two highly developed technologies that have contributed to the understanding of the physics of nozzles are fuel oil burner atomization and gas engine turbine atomization. Some of the major problems with agricultural atomizers are: They require too much energy, have too large a frontal drag area, tend to plug, tend to produce too wide a spectrum of droplets, and have too low a flow rate. One scheme for classifying atomizers is according to source of energy input. The classification simplifies understanding of the basic droplet formation mechanism and limitations of each type of atomizer. The major types are: pressure, rotation, gaseous, vibration, and electrical.

Pressure Atomizers

The simplest is the flat fan nozzle. The liquid is forced under pressure through an elliptical orifice forming a sheet. The sheet is unstable and forms solid streams or ligaments that are also unstable and disintegrate into droplets. If the sheet is introduced into an airstream, the disintegration is further affected and the droplet size varies inversely with the airspeed. The flat fan nozzle produces a wide droplet spectrum and is subject to plugging at smaller sizes.

The hollow cone nozzle has a swirl chamber that imparts rotational velocity to the liquid, resulting in a spray pattern that begins as a conical sheet and breaks into ligaments and droplets as it is subjected to air shear. It has a large orifice due to the air core and is less subject to plugging than the flat fan. It is also simple, but produces a wide droplet spectrum.

The plain jet nozzle introduces the liquid as a solid unstable stream that breaks into droplets. It plugs easily and for that reason is not useful below 700 micrometers. It has the advantage of producing uniform droplets of a large size that fall fast and are little subject to drift.

Rotating Atomizers

The rotating disk was first used as a laboratory device to produce uniform sized droplets. Liquid is introduced onto the face of a horizontal rotating disk. The liquid is thrown from the disk in uniform ligaments break up into uniform droplets. If the flow is too high, a sheet formed instead of ligaments and a wide spectrum of droplets produced. Adaptation of the laboratory device has been made by using multiple disks to increase the total flow rate. Vanes, channels, and serrations have been added to reduce the flooding. At low flow rates they produce a narrower droplet spectrum than the flat fan in hollow cone nozzles, but as flow rates increase, the differences diminish. Most of the rotating atomizers are less affected by forward airspeed variations than the pressure nozzles and are able to produce smaller volume median diameters without plugging at low speeds. For this reason they are very useful for ultralow volume spraying.

Another variation of the rotating atomizer is the rotating sleeves. The sleeves are either screens, perforated cylinders, or porous cylinders. They are subject to most of the same limitations as the spinning disks. All of the rotating atomizers have had difficulties because of bearings, seals, and balancing. Some manufacturers produce well-engineered designs that greatly improve reliability

Gaseous Energy Atomizers

The most common gaseous energy nozzle is the two fluid nozzle. Usually one fluid is liquid and the other is air. The mixing can be accomplished either internally or externally. Some nozzles of this type have been produced for agricultural spraying. They are useful for producing very small droplets with minimal plugging. They do consume very large quantities of low pressure air. When a flat fan nozzle or even an open pipe is used in a high speed aircraft, it becomes a two fluid nozzle as well as a pressure nozzle.

Vibration and Electrical Atomizers

An example of this type of nozzle is the hypodermic needle that produces a fine stream and is subject to vibration. Droplet size can be varied by needle diameter and vibration frequency. This is a low output device and is used in laboratories to produce uniform size droplets. Some other experimental devices using vibration have been developed with higher flow rates. Another laboratory device is the ultrasonic ring driven by a piezo-electric transducer. It also produces small uniform droplets, however, it is subject to clogging.

Discussion

The flat fan nozzle is commonly used for insecticides, while the hollow cone nozzle is preferred for herbicides. Rotating nozzles are coming into use on slow flying (less than 90 mph) aircraft to achieve smaller droplet sizes. They also produce less variation in droplet size due to varying airspeed. There is an abundance of information on droplet spectrums from various nozzle tests. The information is difficult to compare because standard test methods are lacking. Recently, Colorado State University and the University of New Brunswick have done wind tunnel characterizations of flat fan and rotating nozzles. Both tests appear to be well done, but there is some discrepancy in results. This is a common problem of long standing in aerosol work and has been attributed to bias in sampling the spray cloud and different techniques for measuring droplet size.

A new nozzle that would have a high flow rate, be mechanically reliable, not be subject to plugging, reduce the small droplets that are numerically abundant and contribute to drift, and reduce the very large droplets that represent overkill would be the major break through in aerial application. It also appears that significant advances will not be made by gadgeteers, but will require physicists and engineers to design new nozzles based on knowledge of droplet formation and physical principles. Of the energy consumed by the nozzle, usually 2 percent or less contribute to the formation of droplets.

Nozzle and Spray Boom Location

Aircraft moving through the air cause a massive movement of air that is not random but can be measured and observed and follows predictable paths. The two dominate features of the movement are: (1) displacement of a large volume of air downward, and (2) creation of a very stable and persistent rotating cylinder of air from the airfoil tips. The cylinder, or vortex, measures several feet in diameter and contains much of the fine spray. Various models and descriptions of the wake and vortex have been derived and compared to test observations. They are usually as simplified as permitted by the nature of the use of the information, such as affect on aerodynamic lift and structural integrity or persistence of turbulence at airports.

Without these phenomena, location of booms and nozzles would be optimized according to flow rates, structural weight and stiffness, and pilot convenience. Instead, the affect of the air movement on spray movement is the dominant factor in selecting boom and nozzle location. The goal is usually to maximize swath width, reduce entrainment of small droplets in vortices, and to achieve uniform spray pattern across the swath.

Once a boom location has been selected, the spacing of nozzles usually is established by observing uniformity of coverage on ground cards and moving or adding nozzles to maximize uniformity. Booms have been located above the wing, at the trailing edge of the wing, below the wing, and the wing surface itself used as a dispenser. In the case of the helicopter, the boom is usually several feet below and sometimes ahead of the airfoil. Use of a slung bucket can even move the boom farther from the airfoil.

In rowcrop spraying, the boom is usually less than the total wing span to avoid vortex entrainment and reduce drift. There is some question of the effectiveness of this in forest spraying because the vortex appears to be useful in bringing the spray to the canopy top. Some forest insecticide projects have been done with the externally slung booms.

Several investigators have developed a model that predicts the path of a droplet based on size, density, boom location, and wing tip vortex; it has been experimentally verified. Recently, NASA, has conducted wind tunnel tests for the purpose of measuring the wing tip vortex and droplet motion released from a model aircraft. This technology will further refine the numerical description of vortices and increase validity of spray models. University of New Brunswick is currently measuring wake and vortex strength of TBM spray aircraft with instrumented towers in the forest. Spray behavior is frequently interpreted in terms of the visible spray cloud. This is only a small percentage of the total mass and can be misleading.

Pumps, Hoses and Tanks

Spray systems are available from several spray manufacturers for most aircraft. These are well-designed systems for the intended purpose and are adequate with the exception of the nozzles. Some problems are encountered with worn out and home-built systems. Some tank mixes have corrosive and detergent action and the proper material for the spray systems are not called for in the aircraft contract.

Spray System Performance Evaluation

The classic method of spray aircraft performance evaluation has been to fly over a row of ground deposit cards. These cards are then studied for droplet size and uniformity of coverage. The American Society of Agricultural Engineers has recently adopted a standard method for this. The Forest Service Forest Insect and Disease Management Staff has published a manual for a standard method for quick characterization of spray behavior before beginning a spray project. Both standards are somewhat limited in analyzing the behavior of sprays if volume median diameter is less than 250 micrometers. This is because of the extreme variability and the important effect of meteorological conditions on spray behavior.

In addition, methods developed for rowcrop spray purposes may be inadequate for forest spraying. Forest spraying is generally done at 50 feet above the trees. For this reason the characterization flights are done at 50 feet above ground level. The aircraft weight and wing tip orifices have a downward motion and a rotational motion. As this mass of air, which is also affecting the spray, approaches the ground and is deflected outward because of the interaction with the ground it can cause a spreading of the spray swath that does not occur in real life when the only interaction is with the sparse tree crowns of the forest.

AIRCRAFT GUIDANCE

The major problems of aircraft guidance occur in mountainous forested areas. Any number of adequate marking techniques are available for spraying rangelands and other relatively flat and open terrain. When high application rates are used, excessive ground deposits may be of sufficient contrast to untreated foliage to act as guidance. Colored flags or streamers may be positioned to indicate swath widths, assuming wind direction is predictable. Ground flagmen (crew of two) pacing off swaths at the edges of the treatment area are often used with impressive accuracy. For obvious reasons toxicity of the material being applied must be taken into consideration before this technique is employed. Automatic flagmen--aircraft-mounted devices controlled by the pilot--are practical when the terrain does not have a "deep" (10 to 12 inches) or dense plant cover.

Maksymiuk[1/] reviewed the techniques for forested areas. The most often-used technique is to place multi-colored banners (red, fluorescent orange, white, yellow) in the tops of trees, usually at the four corners of a rectangular spray block or in prominent topographic features such as rock outcropping, open ridges, etc. This may be adequate for boundary marking, but unless two or more markers can be seen at the same time they do little to guide swathing. Markers are placed in the tops of trees using a wide variety of equipment. Cross-bows or line-throwing guns are preferred for tall trees (over 100 feet high), where as sling shots or long-bows may be used for shorter trees. In either case, plot and boundary marking is costly and usually several markers must be replaced immediately before spraying because they have blown out of the tree or the pilot is unable to see them.

Helium-filled balloons or kytoons are also used on occasion, both for boundary marking as well as swath marking. Their major drawback is they are easily burst when placing them as boundary markers or when carrying them from point to point in delineating swaths.

Painting the tops of prominent trees by leaning out of a helicopter or throwing weighted banners from a hovering helicopter into the tops of prominent trees are other techniques that have been used. These aerial marking techniques are costly and further limited because of their inherent danger.

Various means of smoke releases have been attempted. These have ranged from placing smoke bombs in boundary corners to mounting smoke-generating machines in aircraft for swath guidance. The effects of airmass movement on smoke make its use as an aircraft guidance technique quite limited. Chase planes are commonly used for guidance but with varying success.

1/ Maksymiuk, Bohdan. 1975. Marking methods for improving aerial application of forest pesticides. USDA For. Serv. Res. Note, PNW-262, 10 p.

The Forest Service Missoula Equipment Development Center has experimented with using a closed circuit TV camera located in a stationary platform over the treated area. The camera is mounted in a helicopter that hovers over the spray area as it is being treated. The camera operator then traces the path of the spray aircraft with a grease pencil directly on the TV screen. If it deviates from parallel swaths the observer can radio this information to the spray pilot for corrective action. The major problems encountered were for the observing helicopter to maintain his exact location and the small field of vision of the TV camera.

Through the years various airborne navigation techniques have been attempted with little practical success. With the fairly recent advances in miniature computer and electronic systems, several new aerial guidance systems appear to lend themselves to use in aerial application. Inertial Guidance System (INS) in principle is derived from laws of mechanics and is one means of navigation that is completely self contained. Basically, INS consists of three mutually perpendicular accelerometers mounted on a platform kept level by gyroscopes; INS is integrated with a computer to give an initial reading of velocity and a second input to resolve distance along the axis of the acclerometers. The computer processes this information to give an X and Y position with respect to a set of original coordinates. Distance and bearing to destination or way point, cross track error, and steering information can also be derived. Results using computer systems in both Canada and Maine to include grid guidance have been mixed. The system is quite expensive to use because of the extensive program writing and data processing of coordinates necessary to operate on a grid basis.

Radio Navigation Systems

Essentially the radio navigation systems available can be classified into two broad categories (1) hyperbolic and (2) Range-Range.

The hyperbolic system receives its name from the fact that the receiver measures the difference in arrival time of signals from two stations, which by definition generates a hyperbola. If the receiver measures the difference in arrival time from a second pair of stations, another hyperbola is generated and where these hyperbolas cross defines the location of the receiver. One station (master) can be common to both pairs of stations, thus requiring only three stations to determine the receiver location. As the location of the receiver is determined by the intersection of two hyperbolic lines, this intersection should be 90 degrees for best results. Some of the present radio navigation systems in the hyperbolic category are Decca, Omega, and Loran-C.

In the Range-Range system, the elapsed time required for the receiver/transmitter to send out a signal to a reference station (transponder) and the transponder to send one back is measured and converted into distance or range (similar to radar). A second reference station (transponder) is used to obtain another distance or range. Then, knowing the distance between the two transponders (measured previously) and the two ranges (hence the name Range-Range), the position of the receiver/transmitter can be determined by trilateration techniques. Most systems in the Range-Range catogory, such as Motorola's Mini-Ranger Airborne Positioning System and the Del Norte Technology, Inc., Trisponder Position System, have the capability to use more than two transponders for more efficient operation.

Generally, the hyperbolic systems operate in the lower frequency range, while the Range-Range systems operate in the higher frequency ranges, both with advantages and disadvantages. The lower frequency signals generally have greater range, are not adversely affected by mountainous terrain or trees, but require a large complex antenna system to transmit. Consequently, the transmitting stations are normally permanent installations; however, there are small portable stations available for both Decca and Loran-C systems.

The high frequency signals are generally short range, up to 50 miles and are line-of-sight. This means there can be no obstructions such as mountains, trees, or aircraft structures between the transponder antenna and the receiver/transmitter antenna. With the shorter range and the necessity of frequently moving the reference stations, they are made very small, lightweight, and portable.

Omega is a worldwide system with eight permanent stations (only seven are in operation) strategically located around the world to provide global coverage. This system was used in the northeast U.S. without success. Decca provides coverage primarily in Northern Europe and other countries using permanent stations. However, a system is available for agricultural spraying operations using portable stations. It has an operating frequency of 1600 to 2000 kHz, uses an interrupted continuous wave-type transmission, and has a typical operating range of 25 miles with an anticipated accuracy of approximately 6-1/2 feet. This system has been used in the South with limited success.

Loran-C is a Government-operated system. It currently covers the east coast, west coast, Gulf of Mexico, and Alaska with coverage extending inland for hundreds of miles. Plans are currently underway to expand the system by adding stations in the mid-continent area, which will provide complete U.S. coverage. These are large permanent stations; smaller portable stations are available.

Loran-C has not been used as a navigation system for spray aircraft, but systems are available for this purpose. The two Range-Range systems, because of their light portable reference station, can be easily moved from area to area, but the line-of-sight requirement can be a problem, especially in mountainous terrain. The two systems are being tested in both the Eastern and Western United States.

The following are some of the characteristics of the various radio navigation systems:

<u>Omega - (hyperbolic system)</u>

- Very low frequency (VLF) 1014 kHz signal.
- Continuous wave (CW) phase comparison system.
- Eight permanent stations provide worldwide coverage.
- Skywaves normally used.
- Diurnal and seasonal variations in signal.
- Estimated system accuracy, 12 nautical miles.

<u>Decca - (hyperbolic system)</u>

- Low frequency (LF) 70130 kHz signal.
- Continuous wave (CW) phase comparison system.
- Decca chain normally consists of four permanent stations.
- Portable stations available.
- Nominal range 250 miles (usable range is determined by skywave contamination of the ground wave).
- Estimated accuracy 60 to 300 feet.

<u>Loran-C (hyperbolic system)</u>

- Low frequency (LF) 90 to 110 kHz signal.
- A pulsed, phase comparison system.
- Permanent stations operated by DOT.
- Portable stations available.
- Typical range, 600 to 1,400 miles.
- Repeatable accuracy, 60 to 300 feet.

Trisponder Positioning System

- Range-Range system.
- Super high frequency (SHF) 9300-9475 MHz.
- Line-of-sight system.
- Portable reference stations.
- Estimated range, up to 50 miles.
- Estimated accuracy, 10 feet.

Mini-Ranger Airborne Positioning System

- Range-Range system.
- Super high frequency (SHF) 5450-5600 MHz.
- Line-of-sight system.
- Portable reference stations.
- Estimated range, 23 miles.
- Estimated accuracy, 10 feet.

To materially improve the capability of guiding spray aircraft over mountainous terrain the "system":

- Should be operable in mountainous terrain guiding aircraft at speeds from 40-150 mph, at altitudes up to 8,000 feet and at heights above the canopy of 30-100 feet.

- Should be able to assist pilot in flying parallel swaths of a predescribed width preferable with parallel contour capability.

- Should be able to reposition aircraft over an unfinished swath.

- Must be reliable and must not require extensive pilot manipulation while in flight.

- Must be capable of being updated to account for irregular plot boundaries or intrusion of sensitive areas.

- System should be able to operate on large blocks (>1,000+) and smaller areas (20-100 acres).

APPLICATION STRATEGY

Application strategy is simply a plan for the efficient use of a pesticide consistent with the present state of the art. It involves the knowledge base developed from past projects, combined with current technology and new developments. It includes all factors that should be considered in conducting a spray project, such as meteorology, entomology, economics, personnel, logistics, etc.

Since 1921 and the beginning of aerial application in the United States, an enormous amount of information has been generated on the subject. The problem has been how to collect and organize this information in a suitable manner for the practitioner. Much of the detail and complexity of the problem is included in other sections of this study dealing with meteorology and spray behavior. By bringing this existing knowledge base to aerial application projects we will be able to plan, conduct, and evaluate in a more efficient, effective, and economical manner, while reducing potential impact on the environment.

The three most significant statements relative to this problem are:

- More knowledge must be developed to optimize the procedures and strategies for applying insecticides.

- Available knowledge is not being fully or uniformly used for application strategy.

- Several different Forest Service groups have developed different procedures for application strategy and the procedures are not standardized or agreed upon.

A scenario is presented below as an example of spray strategy procedures used on one spray project. Although it does not represent a complete strategy, it gives an example of the state-of-the-art as practiced in the field:

- Meteorologist studies weather patterns (wind direction, wind speed, temperature) and topography of the area.

- Pilot flies a reconnaissance of each spray area prior to the day of spraying, and submits a map to project director that includes such things as selected spray direction and length and order of spray swaths.

- Project meteorologist and project director review the flight plan and give the pilot an estimate of windspeed and direction and estimates of when windspeed and direction will change.

- Ridges sprayed during the first 30 minutes of daylight when downslope winds in effect.

- Whenever possible pilot flies aircraft crosswind to enhance overlapping of swaths.

- Windspeeds measured at ground level and 50 feet above the canopy during spraying to determine inversion layer.

- Based on model calculations, the pilot instructed how much to offset from the spray boundary to compensate for swath displacement.

- Special attention given to areas that have converging gradient and slope wind fields.

- Actual swaths flown by the spray aircraft plotted on an aerial photo by an observer in a chase helicopter.

Other groups will have different strategies, depending upon their own knowledge and level of expertise, and the resources available to them, such as experienced fire weather forecasters and experienced spray contractors. Although not reflected in the scenario, timing of application and larval development would be part of developing the strategy.

BIOLOGY & AERIAL APPLICATION TECHNOLOGY INTERFACE

Extensive screening tests to establish lethal dose toxicity values (LD_{50}-LD_{90}) for experimental insecticides and herbicides are the initial tests conducted in the research and development of pesticides for forest use. Usually these tests are simply contact toxicity, i.e., how much active ingredient (AI) per weight of insect or plant tissue is required to kill 50 percent and 90 percent of the test population. These data provide a means to rank test materials as to their inherent toxicity to the test organisms.

With insecticides, additional tests are conducted that test for feeding toxicity, residual activity, "rainfastness," and toxicity when subjected to spray droplets generated from a spray tower.

Materials that survive these testing procedures are then selected for field testing. Among the criteria for selecting materials to be field tested are:

- High toxicity to the target insect.

- Potentially high environmental safety.

- Unusual feeding or residual toxicity.

- Agricultural use or registration pending.

The primary objective in field testing is to define the minimum effective dosage required to provide a given level of foliage protection or population reduction. These judgmental criteria may vary by geographical location, population density, and other management objectives.

Decisions regarding application strategies during the field test stage are based on previous experience with the target insect, forest stands, characteristics of the target, and the material's use history in agricultural spraying.

During the actual field experiment, data are gathered on population reduction of the target insect, foliage protection, and efficiency or effectiveness of the pesticide application. Relative to application effectiveness, data of interest, include volume median diameters, drops/cm^2, and volume deposited per acre. A number of sampling techniques are used to obtain these data and have been discussed elsewhere in this problem analysis. The primary reasons for collecting deposition data are for the investigator to conduct a regression analysis, i.e., dose/response analysis similar in nature to the laboratory-based toxicity tests.

PESTICIDE SAFETY

Although procedures and methods for insuring personnel protection and environmental safeguards against pesticides are somewhat standardized Forest Service Manual (FSM), Title 2100 Environmental Management, Chapter 2140 - Pesticide-Use Management--they are still not given sufficient emphasis on pilot and operational aerial spray projects. There exists a continual hazard to persons who handle pesticides. The extent and magnitude is not always known. Further, there may be a long-term risk to low levels of pesticides over a long period of time. Until the risk is established, methods should be provided as guidelines to insure that personnel, both on and off the project, are protected from direct contact with pesticides. Unless proven otherwise, it must be assumed that all pesticides are hazardous and personnel protected accordingly.

Pesticide Safety in Aerial Application

With the passing of the (Federal Environmental Pesticide Control Act of 1972, the Forest Service sought to place pesticide use management responsibility under one division (State and Private Forestry) and to provide guidelines on policy and use within the Forest Service Manual. After many drafts, FSM 8540 was issued in October 1976 as a chapter in Title 8500-Environmental Management. In March 1978, 8540 was changed to FSM Chapter 2140, Pesticide Use Management, under Title 2100-Environmental Management.

Interim Directive No. 1, issued April 27, 1978, revised Forest Service policy on pesticide-use management. Safety of project personnel and the general public is the main reason for recent revisions in Forest Service policy on pesticide use and for additional interim directives (ID) in FSM 2140, such as ID No. 4, which reflects further review of the information available on possible risks from the use or exposure to 2,4,5-T and related compounds containing the dioxin contaminant 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

Chapter 2140, plus the various interim directives, relates present Forest Service policy on pesticide use, including safety.

This policy is well presented and up-to-date in considering new findings on pesticide safety problems to personnel. If followed, very few serious safety problems will result from pesticide use in the Forest Service. The mechanics of this policy are spelled out in FSM 2140 and will be discussed further as they relate to safety.

The Forest Service requires that a review must be made and approvals must be obtained before applying a pesticide (FSM 2141). These reviews and approvals are required to insure that Forest Service policy on pesticide use is followed. This procedure is adequately described in FSM 2141, and ID No. 4.

This review and approval procedure works very well in most Regions and Areas and has prevented possible serious misuse where the user in the field wasn't aware of potential problems with the pesticide or the application method they wanted to use. This review and approval process must continue to assure personnel safety.

Operational Project Safety Guidelines

Pilot and operational pesticide projects require that a project work plan (FSM 2142.11) and a project safety plan (FSM 2142.12) be prepared before the project is approved. The project work plan must present the organizational and operational details of the pesticide-use project.

Here again, because of possible personnel risks due to TCDD in 2,4,5-T and related herbicide compounds, ID No. 4 revises Forest Service policy to permit the employment of anyone, regardless of sex or age, in any herbicide application activity as long as they are knowledgeable about the information on possible risks. This information must be made available to all force account or contractor employees involved in any way with 2,4,5-T and related compound application projects. FSM 2142.11 (project work plan) was revised in this ID to reflect this safety requirement.

Although the project work plan details the organization and potential pesticide problems involved with the project, the project safety plan details the actual steps to be taken to insure personnel safety and environmental safeguards before, during, and after the project. A safety plan is only required for each major project. All projects involving aerial application of pesticides should be considered major projects for which a safety plan is prepared. ID No. 4 requires a safety plan for any project where 2,4,5-T or related materials containing TCDD are to be used.

Project safety plans are prepared by the project coordinator to insure that the personnel involved in the project: (1) are fully acquainted with hazards of pesticide use; (2) understand the importance of personal hygiene; (3) use protective clothing and devices prescribed on the pesticide container or required by Forest Service directive; and (4) unequivocally follow label directions. A Job Safety and Health Hazard Analysis to determine protective equipment needs (FS Form 6700-7) is used to provide source data for the pesticide project safety plan.

FSM 2142.12 issues these guidelines for the project safety plan:

1. Designate one person to supervise the use of pesticides, including transporting, mixing, storage, and disposal.

2. Detail action to be taken, during or after the application process, if there is any hint of illness or physical reaction.

3. Provide the name, address, and telephone number of the physician to be contacted in case of illness.

4. Provide the telephone number of the nearest poison control center.

5. Include chemical composition, appropriate precautionary label statements, and registration number of the pesticides to enable prompt and accurate transmission of this information in case of accident or illness.

6. List known antidotes to the pesticides.

7. Prescribe actions to reduce or eliminate possible hazards to man, animals, and vegetation from accidental spills.

8. Prescribe disposal procedures.

The work supervisor should be prepared to render first aid in case of spillage or breakage (FSH 6109.13, sec. 8.31).

The project safety plan is mostly concerned with personnel safety at the loading and spray site and only indirectly to personnel safety offsite. Most of the offsite safety considerations are covered in the project work plan, as are the environmental safeguards.

Project safety and work plans from most of the Forest Service Regions and both the Southeastern and Northeastern Areas have been reviewed for this report. They vary from the absolute minimum of a page or two to very complex operational guides of 100+ pages.

Some of the variability is reflected in the type and quantity of pesticide used, but it appears that the best prepared plans are those done by the Areas (insecticide only) and the Regions having the most problems with the public over pesticide use, mainly the Pacific Southwest (5) and Pacific Northwest Regions (6). The guidelines (FSM 2140) for preparing project work and safety plans are a little on the weak side and could be strengthened to include all the safety factors, especially offsite public safety and environmental safeguards (monitoring).

The operational guidelines and monitoring plans developed by Regions 5 and 6 for aerial applications of pesticides are very good but difficult to follow. They should be reviewed, edited, and condensed into a standardized operational guide for pesticide safety and environmental safeguards (monitoring) among all the Regions and Areas, with provisions for special problems within each Region or Area. The inconsistent use of public and environmental safety procedures or safeguards by different Regions should not be allowed as the public will not tolerate the selective use of environmental and public safeguards according to the intensity of public concern within each Region or Area.

Training

Training personnel involved in pesticide use is basic to accomplishing a safe, effective, and efficient job. Commitment to safety in the use of pesticides can only be obtained when personnel understand the complexity of the task and all possible risks. Forest Service Manual 2143.1 requires that only qualified and/or certified personnel will recommend and use pesticides. Training standards will be equal to or more stringent than those required by State training and certification plans, which are based on the minimum EPA standards. Forest Service Manual 2143.2 requires that Forest Service personnel recommending, supervising, or using restricted pesticides will be certified and/or licensed as required by the States.

Most States have excellent training courses and high certification standards. This policy of State training and certification of Forest Service personnel should be continued and supported. It is also important that Forest Service personnel be involved as advisers and instructors in training sessions and refresher courses given by the States.

Special pesticide training should be provided to personnel involved in pesticide projects, especially aerial application projects to bring them up-to-date on the complexities of the pesticides used, the risks involved, and first aid. Although this is included in most project safety plans, it has not been included in all of them. The safety plan is usually well prepared, but it is not always distributed to the personnel on the project. Pesticide training of project personnel for application projects is an area that has been seriously neglected in many aerial application projects. The best prepared pesticide project safety plans and guides will do no good if they are not implemented in the training process as part of the project.

Procedures and Equipment for Protecting Personnel and the Environment from Pesticides

Pesticide-caused illness and deaths occur each year. Most of these cases are caused by carelessness or by accident. Experience has shown that if proper precautionary measures and label directions are followed, even the more toxic compounds can be handled safely.

Much of the responsibility for safety in relation to pesticide use rests with the handler, user, and applicator. If he is knowledgeable concerning pesticides and observes proper precautions, he can do much to insure safety in aerial applications of pesticides.

Project personnel at the loading site (airport or heliport) have the most potential for critical exposure to pesticides. The pesticide-related activities of unloading, mixing, loading, disposal, and storage are where exposure to highly concentrated pesticides and large quantities of pesticide are most likely to take place through carelessness or accident.

All the project safety plans reviewed covered this area of personnel safety. The procedures and types of equipment to be used in these critical situations are well outlined in FSM 2145.1 - Exposure Through Handling, Mixing, and Application. Most of the pitfalls in personnel protection are also covered in this section. However, chapter 2140 is only about 3 years old and has apparently not been around long enough to be understood and used by all project personnel. Project personnel should have a copy of this part of the FSM (2145.1), or a copy of a more detailed writeup in the project safety plan on the specific pesticides used.

In the past, personnel safety problems have been associated with insufficient knowledge of the possible hazards, risks, and routes of entry of the pesticide being used and/or an overprotection policy of many project coordinators. Education and training of all project personnel as well as the project coordinator will go a long way to overcome this problem in the future.

Overprotection policies by some project coordinators and division directors cause more personnel safety problems than they prevent. This overprotection usually results in use of waterproof clothes and respirators for all personnel coming in contact with the spray without regard to the pesticide used or warm weather. In most cases protective clothing needs to be no more than long-sleeved shirts and jackets or coveralls that are not easily penetrated by pesticides and easily washed. Clothing of project personnel must be changed daily and laundered before wearing again.

When waterproof protective clothing is required, it should be of a lightweight, light-colored rubberized clothing. This causes much less discomfort to the wearer during warm weather than does the heavy, dark rubberized clothing. Waterproof protective clothing, when required, should be worn at all times during exposure because dermal absorption rates are increased by placing clothing over skin or other clothes that have already been contaminated. All waterproof protective clothing and respirators must also be washed after every day's use.

The problems of overprotection by project administrators and insuring that project personnel daily wash clothing and safety equipment in contact with pesticides can best be solved by education and training. Although this is a problem with aerial application projects, it is also a serious problem for ground application projects. Here again, FSM 2145.1 clearly addresses these problems, in addition to prohibiting the pilot from handling any pesticides and how, where, and when respirators are to be used.

Environmental safeguards at the loading site are covered in FSM 2142 through the project safety plan. All the latest project safety plans reviewed contained an adequate section on handling pesticide spills. Training personnel on how to handle pesticide spills is not indicated in most of these safety plans. This is one area that needs to be better covered, because a major spill at the loading site or during transportation to and from the loading site can lead to serious consequences. Quick and decisive action is needed to contain and handle a major spill. The operational guides for aerial applications of pesticides developed by Regions 5 and 6 covered this safety problem adequately.

Storage and disposal guidelines are included in FSM 2145 (2145.3 and 2145.4). These guidelines follow the latest available from EPA and should be considered adequate for most storage and disposal problems. They do fail to give guidance on proper storage of pesticide containers in the field on a temporary basis before, during, and after an aerial application project. Some of the safety plans address this problem, but they are inconsistent with each other. Minimum storage standards need to be developed for field storage of used and unused pesticide containers during an aerial application project. Such standards as a "locked area" (fenced area) with protection from the elements (some kind of cover that doesn't touch the container yet is secure enough not to blow away in the wind) would be considered minimum.

The actual spray areas are also critical to personnel safety during and after aerial application of pesticides. Project personnel within the spray area are adequately covered by the guidelines for personnel safety included in FSM 2145. The problems that existed with personnel at the loading site are also present at the spray site. The solutions are the same: adequate education and training. What is not covered by FSM 2140 is the protection of the public on the spray site. The policy in ID No. 1 calls for posting of appropriate signs indicating the name of the material used and date of application to insure that potential forest users are informed of possible exposure to pesticides. In addition, the project officer will confirm that all persons in or near the treatment area are notified in time to leave the area.

There are no guidelines or standards on how this posting of spray areas is to be done. Region 5 has been doing this for some years on their herbicide projects and their procedures should be reviewed and standardized for use nationwide. This is one of the ways the public can be adequately informed of pesticide use. This should be sufficient to protect the public from contact with the actual spray or spray residues on the spray site.

Offsite safety for aerial application projects is covered for project personnel through project safety plans concerning major spills, airplane clashes, and transportation of pesticides (FSM 2145.2). However, the public safety is not as well covered. The public safety will be somewhat protected by the new Forest Service policy on posting the spray area and contacting people in and near the spray area. As mentioned before, both these procedures will need guidelines and standardized procedures developed that can be used nationwide. Local newspapers and radio stations could also be used to notify the public of spray times on the larger projects. The local newspapers, in addition to public meetings, should also be used to educate the public on why pesticides are used, reasons for selection of the pesticide used, and for safety considerations. Although some of these methods have been used in the past on Forest Service projects, public relations have not been stressed in Forest Service policy on pesticide-use or in the guidelines as set forth in FSM 2140.

Good public relations will go a long way to protect the public from possible risks, as well as provide a better understanding of Forest Service use of pesticides in forest management.

Public safety offsite is usually directly related to pesticide drift, dripping nozzles, and failures to shut off the spray when outside the target area. The most common causes of these errors are: (1) failure to select the most appropriate formulation; (2) failure to observe critical wind velocity or turbulence; (3) failure to spray before emergence of susceptible crops; (4) failure to consider time of day in relation to temperature inversions; (5) failure to consider all adjacent crop, dwellings, and water sources; (6) application from too great a height; (7) application with too high a pressure; (8) failure to prevent leaking nozzles; and (9) failure to shut off the spray distribution at the edge of the treated area.

Drift is addressed in FSM 2144.31 - Aerial Application, where good guidelines are given to prevent drift. But not enough detail is given this very important safety factor. Drift of pesticides offsite is properly the most serious safety problem for the public. More attention should be paid to the factors that cause drift, mainly particle size, range, wind velocity, height of application, and the stability of atmospheric conditions. All the factors that produce small spray droplets, which are highly subject to drift, should be listed with the role they play. Factors that effect spray droplet size, such as high pressure, small nozzle orifice, rotation of nozzle to line of flight, relative humidity, and formulation or additives are so important in understanding the problem of drift.

The problems of drift and environmental monitoring in aerial application of pesticides is well covered in the operational guides for aerial application of pesticides developed and used in Regions 5 and 6. These guides should be reviewed, edited, and placed in a standard format for use by the Forest Service nationwide for all aerial application of pesticides. It is much easier to go into detail in a guide or handbook of this type than in the FSM.

Pesticide safety in aerial application projects by the Forest Service has been good overall. Forest Service policy, procedures, and equipment are up-to-date and adequate. Training is better than in the past but needs improvement, especially specialized training for project personnel and the project coordinator. There needs to be a better understanding of personnel pesticide safety by the project personnel. Knowledge about the hazards and risks of the pesticides used and how safety equipment and procedures reduce hazard and risk is vital to project personnel.

Whenever cholinesterase-inhibiting pesticide materials (mostly insecticides) are used in aerial application projects, cholinesterase blood tests for all personnel should be part of the medical supervision of the project. Cholinesterase tests should be given before the project begins, to establish a "baseline" value for each individual on the project. Whenever the individual cholinesterase level drops below 50 percent of the base-line value, that individual should be removed from contact with cholinesterase-inhibiting materials until the cause has been remedied and cholinesterase levels have stabilized at no more than 25 percent below baseline.

The need for medical supervision and monitoring cannot be overemphasized for projects using highly toxic materials or cholinesterase-inhibiting materials over long periods. Most project safety plans have reference to medical supervision but none of the insecticide projects using cholinesterase-inhibiting insecticides included this important personnel safety procedure of cholinesterase testing.

From a personnel safety standpoint in aerial application of pesticides, FSM 2140 provides very good guidelines, especially if they are strengthened by the suggestions mentioned above. However, FSM 2140 does not provide all the guidelines necessary for proper environmental safeguards and public safety offsite. The Forest Service needs to develop a handbook or guide on aerial application of pesticides that covers in detail the safety problems involved with the public when a pesticide moves offsite: (1) posting spray areas; (2) alerting the public in and near spray areas; (3) public information on the pesticides used and how they fit into forest management; and (4) preventing pesticide drift. A guide or handbook similar to those developed by Regions 5 and 6 needs to be developed as part of Forest Service guidelines for all the Regions and Areas for safety in aerial applications of pesticides.

SPRAY BEHAVIOR

In recent years there has been an accelerated effort in the development of predictive techniques for determining the temporal and spatial distributions of aerial sprays. All of these methods have relied heavily on the modern digital computer. The methods are usually developed by making assumptions concerning the chemical and physical behavior of the spray, expressing these assumptions in the language of mathematics, and translating the mathematical statements into a computer language to obtain a computer program that is then run on a digital computer to carry out the necessary calculations. The results are then compared to experimental data to ascertain the reliability of the entire theoretical construct or model.

There are several advantages to such a process. Some of them are:

1. The very process or act of developing the model uncovers knowledge gaps and reveals misunderstandings in the investigators hypothesized behavior of the overall system. The computer program simply will not run if a part of it is missing. Grotesque results will be obtained if the overall organization or behavior of the system is not properly implemented. The fact that the process of developing a model contributes so greatly to the investigator's understanding of the phenomenon being investigated is well recognized. For this reason many scientists like to say that the purpose of model development is the obtaining of insight about the phenomenon. In other words, the actual process of constructing and checking out a computer model is an excellent method for obtaining understanding of the process being investigated.

2. The ability of the tool so obtained to reveal where further research and development should be carried out. As an illustration, it may be and development should be carried out. Or, it may be thought that spray evaporation rate and turbulence have a significant effect on the determination of the deposition pattern. By varying each of these parameters, it is possible to ascertain the relative effect of each variation on the deposition pattern or on the overall objective of the spray application. In this way it is possible to properly weight the effort to be expended in determining each of the parameters.

3. Such a model can also be used as a quick and cost efficient method for ascertaining the effects of design changes on the overall aerial spray delivery system.

4. The very real possibility of using the model as a tool for designing or defining an effective aerial spray operation. After all, the computer merely carries out at very great speed the consequences of the understanding of the investigator of the behavior of the system.

In this work, the term model is used in the very general sense of connoting a collection of assumptions and the implementation of these assumptions into a computer program. Models for describing aerial spray behavior naturally fall into two categories: diffusion based and ballistic based.

Diffusion models derive from assuming that the primary process describing the motion and behavior of droplets comprising an aerial spray is one of diffusion. Diffusion is a process whereby particles, such as molecules of a gas, intermingle, mix, or exchange positions in space as the result of their spontaneous agitation caused by spatial differences in the concentration of the particles. Denser concentrations of particles are characterized by a greater number of particles occupying a fixed amount of space. The inherent or natural vibration motion of the particles results in particles in a region of space having a large number of particles being scattered and hence moved to a region of space occupied by a lesser number of particles. Thus, diffusion is a one-way process that tends to a state of equilibrium, that is, it tends to a state whereby equal volumes of space are occupied by the same number of molecules.

Diffusion models, because they are realistic representations of the behavior of large collections of very small particles or droplets, are useful in determining the drift of a spray and hence useful in the determination of the environmental impact of a spray. Very sophisticated diffusion models have been developed and are in operation. They are of two kinds. One type is based upon mathematical expressions of the solution of the diffusion equation; these models are usually called Gaussion Plume Models. The second type is based upon a finite difference or discrete model of the behavior of the spray as a diffusion process. In contrast to the plume models, discrete diffusion models are frequently more general and versatile in that they usually provide a more realistic description of the process by their ability to readily include more of the relevant variables and the relevant physics.

The ability of such models to be more inclusive is not without penalty, however, since such models usually require more computer time and more information to effectively run them. In addition, because such models process vast amounts of data, it is not easy to analyze and thoroughly appreciate all of the computer results. All diffusion models predict the temporal and/or spatial concentration of particles, i.e., the temporal or spatial average number of particles per unit volume at a particular point in space at a particular time.

Some of the effects that can be studied with the aid of a diffusion model are the variation in spray intensity due to a variation in atmospheric conditions such as temperature gradients, humidity, wind, turbulence, and topography.

Because many other phenomena, like heat transfer and the mixing of gases, are well described by the diffusion process, there is an extensive literature in the form of tests, treatises, and technical articles that are available for possible application to the analysis of spray behavior when the sprays consist of very fine droplets.

The second common method of the theoretical analysis of aerial sprays is based upon the ballistic model of the behavior of a droplet. A ballistic model derives from assuming that each droplet behaves as if it were a mass moving under laws governed by Newton's laws of motion. By describing the motion of each droplet in this manner and by properly averaging the motions of a large collection of droplets, it is possible to obtain the overall temporal and spatial variation of the spray. Such a technique has been used with great success for many years in reactor physics and in particle physics. It is believed that a ballistic model is appropriate for describing sprays composed of droplets whose radii are larger than 1 micrometer. Consequently, a complete description of an aerial spray comprising droplets whose original sizes were in the tens or hundreds of micrometers down to droplets whose sizes are less than a micrometer requires the use of both a ballistic and a diffusion model.

It is sometimes loosely stated that the deposition problem should be analyzed with the aid of a ballistic model and the drift problem analyzed with the assistance of a diffusion model. In fact, it is quite reasonable to assume that the early time history of spray will be accounted for by a ballistic model. The results of this model will then provide the necessary temporal and spatial droplet concentrations for input to the diffusion model.

In the recent decade several ballistic-type models have been developed and there has been some experimental confirmation of the results obtained from these models. However, much more work is needed to thoroughly assess and confirm the validity and range of application of both ballistic and diffusion models.

Because ballistic models are relatively simple to develop and implement on a computer, they can by readily altered to include many diverse effects believed to be important in governing the behavior of an aerial spray. For example, the inclusion of the effect of the vortices generated by a fixed-wing aircraft while delivering a spray can be readily included in the equations of motion describing the droplet trajectory. Also, the effect of droplet evaporation and the consequent change in both the droplet mass and concentration of pesticide, the effect of turbulence, temperature gradients and humidity all can be readily included in a ballistic model. Such effects are not readily included in diffusion models based upon a particular mathematical form of the solution of the diffusion equation. On the other hand, those diffusion models, which are based upon a finite difference or discrete model, can more readily include such effects. For all models, the inclusion of such effects usually results in a significant increase in computer run time and in the time necessary to set up a problem.

As of this date, there is no single, all-inclusive method for accurately describing the behavior of an aerial spray. As stated above, such a description will most likely be obtained by splitting the time history of the spray into parts and using different sets of assumptions to describe the behavior of the spray in each of the time intervals. Thus, model development is still partially an art as well as a science.

SPRAY DRIFT

Spray drift may be defined as the unintentional delivery of pesticides through air outside of the target area. The problem of spray drift may be separated into two major parts: (1) The true drift is the result of the spray cloud released over the target area and then drifting away. (2) Spraying outside of the spray block because of human errors and equipment failures produces similar results on the ground. It frequently cannot be easily separated from the first type.

The travel of the spray droplets after release from the aircraft depends on external factors that cannot be controlled by man. The large droplets, travel downward because of gravity. Fairly strong winds are needed to displace these droplets from their trajectory. In herbicide application, where large drops appear to be more efficient, drift reduction is achieved through increased droplet size.

For many years aerial application of insecticides was made with droplet sizes over 100 micrometers (volume median diameter). Recent literature indicates that the small droplets may be sufficent to kill the pest. As a result, desirable droplet sizes are decreasing to the 40 to 80 micrometer range. These small droplets are not primarily directed to the target area by gravitational fall. Instead, the droplets are carried in air drainages and by local breezes. The turbulence created above crown canopy when wind is moving over the trees carries the droplets into the crowns where microclimatic airflow distributes the spray cloud. Thus, wind becomes a beneficial and predictable factor in the delivery of small droplets. The practical application of this knowledge is not well incorporated in most of the present operational projects. Application research is needed to prescribe methods for small droplet size spray application.

Most drift prevention attempts are directed at the large and visible droplets. These carry most of the insecticide and herbicide volumes. Near sensitive areas, buffer zones are established that are to provide decreased gradation of the drift away from the spray block. However, inflexibility of large operational projects does not allow for corrections needed because of wind changes. In herbicide application, adjuvants are used to decrease evaporation and reduce the number of small droplets. Dilution of herbicides increases volume of application to achieve the same coverage, but the small droplets that drift away do not carry harmful volumes.

Human errors and equipment failures may deliver pesticides long distances from the target area. Some of the more common errors include inadequate boundary marking, navigational errors, spraying in turns, or late shutoffs. Dripping spraying systems and intentional "testing" and dumps can appear as long distance drift contamination. Most of these errors are reduced by proper planning, expertise in aerial operations, and close monitoring of spray aircraft.

Spray drift cannot be measured with most of the same equipment and methods used to evaluate spray coverage within the target area. Some of the methods are indirect, such as bioassays and behavior observations of plants and animals. The more direct measurements include collection of spray in the spray cloud, on foliage or spray deposit cards, and chemical analysis. A thorough review of drift sampling criteria and standards is presented in the Forest Service Missoula Equipment Development Center report, Criteria and Standards for Drift Sampling Forest Pesticide Spray (7752 2218), October 1977.

While the equipment appears to be adequate for research use, field personnel generally consider it cumbersome and expensive. Spray monitoring is done within the target areas and near very sensitive areas outside. Monitoring seldom includes systematic measurement of drift in all areas outside of the spray block.

Lack of monitoring of spray drift exposes project managers to unwarranted claims of contamination. Some sort of maximum acceptable standards of pesticide contamination need to be established, and then monitoring maintained for compliance. Usually, the applications staff and aerial contractors do not consider drift a serious problem, unless extremely sensitive areas are involved. Inflexible buffer policies establish zones where spray craft should not be spraying, but do not provide assurance that that drifting into the area will not occur. Monitoring for compliance to a given standard will require use of available knowledge on meteorology and spray delivery.

SPRAY SAMPLING

Introduction

The science and art of sampling aerosols, sprays, and particulate material have been developed primarily in response to air pollution and weapons research. The London and Donora smog episodes of this century alerted the public to the need for air monitoring. Since the 1940's considerable research has been sponsored by Defense agencies in developing samplers suited to collecting and quantifying nuclear fallout and chemical and biological sprays. Cooperation among the U.S. Public Health Service, Department of the Army, and the Department of Energy has provided an array of samplers, sampling equipment, assessment techniques, and methods that cover monitoring of particle sizes ranging from submicron to greater than 1,000 micrometers in diameter, and including inorganic, organic, liquid, dry, inert, and live substances.

There is a serious lack of statements and specifications for levels of detection needed or required of pesticides applied aerially by the Forest Service. Agencies that need spray deposit and air concentration data for legal, political, technical, etc., reasons must specify the levels before the Forest Service can select and deploy appropriate samplers and provide the requisite data.

The Forest Service has a need to collect and quantity a variety of pesticide sprays consisting of particles ranging in size from a few micrometers to several hundred in diameter. The need to sample sprays can be included in one of these three main categories:

1. Documentation

   Contract performance

   Legal consideration

2. Technical

   Analysis of results

   Project management

   Testing/Development

   Equipment performance

   Spray strategies

   Spray Strategies

   Spray accountancy

   Spray dispersion model development and validation

   Drift monitoring

   Sampler evaluation and modification

   Dose/Mortality studies

3. Environmental Studies

Basic Sampling Methods

Sampling pesticide sprays can be either qualitative (Did the spray reach this position?) and/or quantitative (How much arrived at this position?). Depending upon the type sampler used and the supporting equipment, additional data can be obtained, such as when and how much spray arrived in what particle sizes. The technology of spray sampling has progressed and made available samplers, sampling equipment, and methods to satisfy most Forest Service needs.

Here are the basic sampling methods:

- Impingement in liquids. Uses principle of impingement in which particles are entrapped in a liquid medium. The most commonly used sampler is the glass bubbler or impinger. Air is drawn into the sampler at high velocities with the particles impinging on the liquid medium. This can be a highly efficient method of sampling. Support equipment such as vacuum pumps, need for ac or dc electrical energy sources, weight, and cost are disadvantages of this method.

- Impaction on solid surfaces. There are two types of sampling with this method: impaction by means of wind or inertial forces of the particle and impaction resulting by vacuum or suction devices. An example of the former would include variously shaped objects that are presented to the airstream. The collection efficiency of the object can be calculated by knowing the particle size distribution of the spray, size and shape of the object, and the air velocity. This can be a very inexpensive method of collecting spray and is particularly suited to qualitative sampling. The second method usually involves impaction on a flat surface such as a metal or glass plate. Air is used to pull the airborne sample on the plate. Vacuum pumps are usually used. When the air drawn past the collecting surface is measured, the sampler can serve as a quantitative sampler. The Anderson and Cascade samplers are examples of impaction type samplers.

- Filtration. Sampling by filtration is one of the most commonly used methods. Again, a vacuum source is used to pull air through a fibrous filter. This can be a highly efficient sampling method. Spacing between the filter elements dictates the size particles that will be collected. Assessment of the filter is relatively easy. Particles are assayed chemically, physically, or biologically. Filtration is a simple and relatively inexpensive sampling method suitable for chemical and biological sprays. This can be a quantitative method when the sampling unit is calibrated for proper flowrate.

- Sedimentation. This is a simple method of sampling airborne particulates whereby particles settle on a flat surface such as paper, glass, or metal. This method provides only a qualitative sample of the airborne concentration, and is more efficient for particles with a high settling velocity. This is the method most commonly used by the Forest Service to sample both chemical and biological sprays. Paper Kromekote cards are the standard sampler for Forest Service pilot and operational control projects. Metal plates are used on some field experiments to collect and assay through plate washing the deposited particles. Natural surfaces such as leaves can be used also as sedimentation samplers.

- Centrifugation and electrostatic or thermal precipitation. These methods of sampling are not considered suitable for Forest Service operational use due to either cost, complexity, or limited sampling range.

The Forest Service employs a variety of samplers, depending on whether it is an experimental, pilot, or operational spray project and the type of data needed. Nearly all sampling on these projects is done to detect what is settling to the ground or the target.

Metal plates, film, and foliage are used on experimental projects to collect the deposition of spray droplets for chemical and tracer analysis. White Kromekote cards are the most commonly used deposit samplers for all projects when dye is added to the spray.

Deposit-type samplers are suitable for quantitating the amount of spray volume being deposited on a surface or surface area. Depending on the type samplers and the method of analysis, data can be obtained also on drop size.

Other types of detection papers have been used to collect pesticide sprays. None, other than the white Kromekote card, has been standardized by Forest Service operational use.

Sampling Equipment

Sampling equipment is the auxiliary materials and the hardware necessary to house, power, and operate samplers. As an example, a Millipore filter sampler would usually need a holder, vacuum pump and tubing, calibrated orifice, and energy source such as a battery, generator, or direct current to operate as a sampler. Equipment often is the limiting factor in selecting a sampler due to cost, weight, complexity, availability, and maintenance.

Particle Sizing

Samplers and sampling methods are available for determining spray particle size. Several problems persist in this area and at present no satisfactory method is being employed in the field by the Forest Service to determine both qualitatively and quantitatively the number and size of particles in a spray. Kromekote card samplers are limited in their use to that portion of the spray that settles to the ground. Assessment of fine particles on Kromekote cards has proven challenging. Laser and light scattering devices show promise for field use in describing spray being emitted from nozzles, particles which are settling and impacting on biological targets, and those which are drifting off the target. Considerable work is needed in the area of particle sizing and spray accountancy.

Considerations for Sampler Selection

There is a wide variety of samplers and sampling equipment available. Selecting the proper combination depends upon the objective of the sampling plan, data required, and nature of the pesticide. Factors to be considered are:

1. Type of pesticide to be collected.

2. Sensitivity of particles to sampling.

3. Assumed concentration and particle size.

4. Volume of air to be sampled and length of time sampler is to be continuously operated.

5. Type of background contamination.

6. Atmospheric conditions.

7. Sampler collection efficiency.

8. Effort and skill required to operate sampler.

9. Availability, maintenance, and cost of sampler and associated equipment.

10. Personnel availability.

11. Assay methods available or to be used: chemical, physical, or biological, and use of tracers or dyes.

12. Terrain.

Conclusion

Agencies with legal responsibilities for determining levels of pesticide detection and/or monitoring by use of field sampling equipment must specify levels to project manager. This must be done before a sampling plan can be developed and appropriate samplers selected.

Many types of samplers are available to collect pesticide sprays. Forest Service needs can be satisfied with existing samplers and auxiliary equipment. Samplers and equipment applicable to Forest Service needs should be identified. Quantitative sizing of pesticide sprays is the most challenging in terms of applying existing technology. More emphasis must be given to spray accountancy. Selection of a sampler for a particular application depends upon many factors, however, with cost and logistics being two major and often overriding factors.

MOUNTAIN WIND

Introduction

The literature on evening and morning mountain winds is voluminous and reaches from purely descriptive reports to extensive numerical simulations of airflow around real or idealized topographic features. The difficulties in the first extreme arise in trying to isolate some results that are independent of the site, and in the second, of distinguishing the physical assumptions from the numerical techniques.

Both types of study are repeated only with considerable effort. The first because of the time and expense involved in such field studies and the second because of the considerable time required to construct a working computer program or to transfer a particular program to another computing system.

This review emphasizes mathematical models of the mountain surface wind field under conditions typical of aerial applications with little, if any, attention to wind tunnel modeling or the lee wave problem. The relevance of either topic to spray applications appears to be minimal.

This review is an attempt to describe the state-of-the-art of mathematical modeling of windflow over mountains under stable conditions in nonmathematical terms and with minimum documentation. The basic physical relations are discussed, some common approximations outlined, and a few typical models described.

The Conservation Equations

Most predictions of windspeed and direction are based on the solution of one or more of three conservation equations: the mass balance, the momentum balance, and the heat content balance.

The mass balance may be qualitatively written as:

(rate of local density change) = (net density advection) (1)

This balance is written for a unit volume fixed in space and for a particular time.

The net density advection is the difference between the mass moved into the volume by the wind and that moved out.

Local density changes can be due to changes in total pressure or in air temperature in accordance with the familiar ideal gas laws.

If the coordinate system chosen is the common "geographic system" with one coordinate along the vertical and the other two lying north to south and east to west, then equation (1) is often written as:

(density) x (horizontal) = -(vertical net density advection) (1a)

The horizontal divergence can be defined as the expansion in the horizontal plane of a unit mass of air as it moves with the wind. Equation (1a) is derived from equation (1) by making what is sometimes called the "anelastic" assumption. This approximation neglects the point-to-point deviations in air density at the same elevation is compared to the much longer variation of air density with height.

A more severe approximation, which has been made in many of the mountain wind models, is the assumption of incompressibility, i.e., even the vertical variation of air density is neglected for the mass balance, resulting in

(horizontal divergence) = -(rate of vertical velocity increase with height) (1b)

or

(divergence) = 0 (1c)

where the divergence refers to the rate of change with time of the total volume of a unit mass of air.

For mountain windflow models that neglect the movement of heat from the surface to the overlying air and neglect the aerodynamic drag extended on the wind by the terrain surface, geographic coordinates are probably most useful, and the relation (1a) is an appropriate form for the mass balance. For more general models, these coordinates yield complex expressions for the lower boundary conditions and the "sigma" coordinates described below become preferable, even though their use in really mountainous terrain requires the general statement of the mass balance as in equation (1) rather than equation (1a).

The momentum balance may be written

(density) x (acceleration) = (Coriolis force) (2)
+ (pressure gradient)
+ (turbulent stresses)
+ (gravitational force)

There are three momentum balance equations to be considered corresponding to the three wind velocity components needed to describe the airflow at any point. For this discussion these components are: the north-to-south component in a plane tangent to the terrain surface; the east-to-west component in the same plane; and the air movement perpendicular to the terrain surface, called the normal velocity.

The acceleration is the rate of change of a unit volume of the air. It can be decomposed into:

(acceleration) = (local acceleration) (2a)
+ (curvature terms) + (advection)
+ (density variation terms)

The advection terms are similar to those of equation (1). Typically they are proportional to the rate of variation of the velocity with downwind distance times the velocity.

The curvature terms are "apparent" forces, for example, centrifugal forces that arise when a coordinate system of this type, i.e., sigma coordinates, are used. The magnitude of these forces is inversely proportional to the radii of curvature of the terrain and directly proportional to the square of the windspeed in the plane of the curvature. For large radii, such as for a level plain, they can disappear in relation to the other terms. For small radii, such as at a peak or ridgetop, they might dominate the flow.

The local acceleration is the rate of change of the wind velocity component at a point.

The density variation terms are proportional to the velocity components and the variation of density with distance along the component direction.

The Coriolis force is an apparent force due to the earth's rotation. Its action is confined to the horizontal plane, but for "sigma" coordinates Coriolis terms would appear for all components. Its effect is to deflect the wind toward movement along the isobars. The steady windspeed and direction that would result if only these two terms were present in equation (2) is called the geostrophic wind. The height at which the wind attains the geostrophic value is often called the mixing level.

The pressure gradient term can be expressed as the sum of a large scale gradient, i.e., the synoptic gradient for the two velocity components in the tangent plane and localized dynamic gradients.

The earliest models for down-valley and downslope winds considered valleys and slopes of infinite extent. There were no downwind variations in velocity and consequently no advective terms. A few later analyses also drop them for finite terrain features. In general, nonadvective models would seem plausible for terrain with only slight nonuniformity, unless the surface is extremely rough. Explicit studies on the limits of this approximation are few; one recent calculation suggests that for moderately mountainous terrain the advective terms are entirely comparable to the local pressure gradients.

The curvature terms have been uniformly neglected in the models encountered in the literature. No estimates of their magnitude for typical topographic features appear to have been made.

The local acceleration is obviously neglected in the "steady state" mountain wind models. Where unsteady mountain flow models have been reported, the time variation has often been incorporated in the conditions at the boundaries of the area of calculation.

Density variations due to dynamic pressure gradients are neglected in all the models; the relative density variations are expressed in terms of the local temperature variations, a procedure that seems sound for any conceivable mountain wind regime.

The Coriolis force terms can generally be neglected in comparison with the local pressure gradients near the terrain surface, they are commonly small compared to the tangential shear stress terms in the boundary layer where they are considered. In the models encountered, they appear only in prescribing the wind at the upper boundary of the calculation, which is often assumed to be the mixing level.

Dynamic gradients are those due to local deflections and retardation of the surface wind by the various topographic features.

The gravitational force is proportional to the sine of the angle that the direction of the velocity component makes to the horizontal and the gravitational acceleration (g), equal to about 980 cm sec^{-2}.

The turbulent stress terms represent the major difficulty in the calculation of the windflow near the terrain surface. They are also difficult to describe in nonmathematical terms for three-dimensional situations. They can be described rather loosely as the result of the transfer of momentum from regions of high momentum along one velocity component direction to regions of low momentum along that direction by small-scale and rapidly fluctuating motions, i.e., in most situations "turbulence". They can be subdivided into tangential, normal, and lateral components in terms of the "sigma" coordinates.

The tangential forces are most familiar under the name of "surface friction drag", and are directed along the tangent plane in the north to south and east to west directions. They are due to the transfer of momentum along the coordinate perpendicular to the terrain. For flow over uniform terrain, they reduce to the surface shear stress, commonly estimated from windspeed profiles.

The normal forces are directed along the three coordinate axes and represent the transfer at momentum for each component by mixing along its axis.

The lateral components are directed along planes perpendicular to the tangent plane and represent momentum transfer along the coordinate axis perpendicular to the plane, i.e., they are similar to the tangential forces.

For airflow on a uniform and infinite slope, the normal and lateral components vanish.

Where the curvature terms are large, a number of corresponding turbulent stress terms are generated that are essentially proportional to the velocities and the intensity of the turbulence.

Three regions are commonly defined for windflow over a rough natural surface: the two regions closest to the surface comprise the boundary layer, the defining characteristic of which is that the normal velocities are so small they can be neglected; the part of the boundary layer next to the wall is the constant shear stress layer or inner boundary layer where the dominant terms are the tangential turbulence stresses.

The outer boundary of the inner layer is generally defined as the normal distance at which the fractional rate of increase of the wind velocity with normal distance falls below about 1 percent in the case of horizontal or isothermal boundary layers. The analogous criterion for tilted nonisothermal boundary layers does not appear to have been derived.

If normal velocities may be neglected, the momentum balance for the velocity component perpendicular to the surface, i.e., the normal component reduces to a balance between pressure gradients, gravitational force, and turbulent stress terms.

The hydrostatic assumption amounts to neglecting the last contribution. This allows the pressure drop or rise across the boundary layer to be calculated in terms of the density distribution across the layer, the boundary layer thickness, and the terrain slope.

At this point it is usual to further assume:

(a) that the air follows the ideal gas laws,

(b) that the pressure variations at the same altitude are small compared to the total pressure (the Boussinesq assumption), and

(c) that the slope of the terrain is slight.

Almost all the models use the hydrostatic assumption. Those that do not, resort to a direct integration procedure that yields an estimate of surface pressure in terms of pressures on the boundary of the calculation area.

Some of the models assume that the velocity profiles across the boundary layer are similiar, i.e., that velocity profiles at different points are the same if the velocity is expressed as a fraction of the velocity at the top of the boundary layer and the normal height as a fraction of the boundary layer thickness. More specifically, a number of calculations assume that the inner boundary layer at least is in local equilibrium. The profile is the same as would be found for an infinite fetch over a surface with the same roughness.

The only turbulent stress term considered in any of the models is the tangential stress term, although some of the smoothing or space averaging carried out during numerical solutions could simulate the effects of the remaining terms. The tangential stress term is evaluated on the assumption of local equilibrium below some fixed reference distance from the terrain. In one case a drag coefficient is used at a constant height rather than a constant normal distance, a procedure inconsistent with a constant shear stress layer adjacent to a tilted surface.

About half the models make no attempt to include the turbulent stress terms.

The dynamic pressures are usually calculated on the assumption that the boundary layer thickness is small compared to the local radii of curvature of the terrain, an assumption more appropriate to downslope and down-valley flows that to the upslope and up-valley winds. These calculations also assume that the turbulent stress terms may be neglected outside the boundary layer. A further approximation is the assumption of irrational flow and constant density outside the boundary layer, i.e., a potential flow.

Where potential flow solutions are not employed, the problem has generally involved some idealized topographic shape, e.g., a bell-shaped hill exposed to a linear upwind profile. These are of limited utility in representing real landscapes.

The potential flow models are based on the method of super position. The topographic surface is regarded as a stream surface generated by the addition of sinks or sources to a uniform stream.

In its most general form the calculation is extensive, but the models examined use either the slender body approximation or the much more approximate duct flow model.

The slender body approximation assumes that the potential, i.e., the source or sink strength required to represent the surface at a particular point depends only on the slope and orientation of the surface at that point. Theoretically the error involved should be quite large for hills or valleys with grades much greater than 2 or 3 percent.

The duct flow calculation consists of assuming a rigid lid at some height above all the features of the terrain. As for the slender body calculation, the vertical velocity (as contrasted to the normal velocity) is estimated as the product of the windpeed at the top of the lid and the grade of the surface in the direction of flow at the lid. The average of equation (1) is taken between the surface and the "lid", resulting in an equation for the average horizontal disturbance generated by the topography at any point in the horizontal plane. The vertical velocity is equal to half the average horizontal divergence.

This "disturbance" is assumed to vanish upwind and downwind of the calculation area. The magnitude of the disturbance depends on the height of the lid; the higher the lid, the less the disturbance.

The calculation can be readily generalized in so far as any distribution of vertical velocities at the surface (on the outer edge of the boundary layer) can be interpreted in terms of an average divergence field. Examples are a plume formulation for vertical velocities due to differential heating, or vertical motions due to changes in surface roughness.

Slender body and duct calculations are usually performed on severely averaged topography, i.e., the terrain elevations taken from contour maps are averaged over blocks by a variety of schemes. The net effect is to reduce a rugged topography with multitudes of canyons and ridges to a smoothly undulating surface that often resembles the sort of surface for which the slender body approximation would be reasonable. The wind field computed for such surfaces is then regarded in some sense as a horizontal average wind. In the case of the duct flow models, this involves separate averages for the slope of the terrain and the height, which occurs as a ratio in the final equation to be solved. If slope and height were independent, this procedure in itself would be unobjectionable, but terrain grade tends to increase with local height. With the possible exceptions of mesa type topography, the plane averaging will introduce a term involving the correlation between the point-to-point deviations of height and grade, a point which does not seem to have received attention.

The problem of estimating the dynamic pressures in realistic topography is complicated by boundary layer separation. When the direction of flow above the surface is opposite in sign to the surface pressure gradient, as may happen to the windward of a ridge or in a narrow canyon, a region of separated flow may form at the surface, i.e., a closed eddy. Such separation will have the effect of smoothing the apparent surface of the upper boundary layer, as well as drastically altering local windspeed and direction at the surface. It has been commonly observed in the field during evening and morning conditions.

The tangential turbulent stress forces have generally been expressed in terms of a drag coefficient on the assumption of local equilibrium in the inner boundary layer, or in terms of the normal velocity profile and an eddy viscosity, a coefficient which relates the tangential shear stress to the change in velocity with distance along the normal to the surface.

Two models use a drag coefficient that is effectively proportional to the windspeed, which is convenient mathematically but unrealistic for most natural surfaces even at the low speeds and high stabilities found in morning and evening surface windflow.

Stability in this context is most commonly defined in terms of the Richardson number. When the variation of wind velocity with downwind or crosswind distance is slight, i.e., for uniform flows, and when the surface is cooling at a moderate rate, the Richardson number specifies the ratio of turbulence dissipation to its production. It is commonly calculated from the ratio of the temperature rise per unit normal distance from the terrain to the square of the corresponding wind velocity increase. An additional factor is the gravitational acceleration multiplied by the cosine of the slope angle to the horizontal. The temperature rise must also be connected by a small amount corresponding to the adiabatic lapse rate defined below.

Both drag coefficients and eddy viscosities decrease as the Richardson number rises above zero and increase with increasing surface roughness. When the index approaches about 0.2 over a particular height interval, the eddy viscosities approach zero and the drag coefficients for levels above that interval drop to nearly zero. This appears to be the approximate situation for the well developed downslope flows found in the early morning in mountainous terrain with clear kies.

For more complicated situations such as down-canyon flows where wind velocities and temperatures may vary both downwind and crosswind and where wind direction may change sharply with height, the Richardson number may not be either defined or relevant to the estimate of the turbulent stress forces. A more general index is needed, but none has attained any wide spread acceptance.

Few of the terrain flow models attempt to simulate the effects of surface cooling on the eddy viscosities or drag coefficients and in many calculations the introduction of these parameters is arbitrary and oriented toward computational problems.

The heat balance for a unit mass of air may be written as:

(cooling) = (loss by turbulent conduction)
+ (net radiation loss) (3)
- (condensation heat release)

The cooling may be resolved into:

(cooling) = (loss by advection) +(local changes in heat content) (3a)

The sensible heat content (to be distinguished from the enthalpy) is commonly expressed in terms of the potential temperature. The potential temperature is the temperature the unit mass of air would attain if it were compressed without loss of heat, e.g., in an insulated box, to sea level atmospheric pressure and without condensation or evaporation of any of its water content.

Thus, the cooling team refers to the rate of change of the potential temperature of the unit mass of air multiplied by an effective specific heat.

In an atmospheric layer with a uniform potential temperature the change in actual temperature with height would be about 1^{o} C per 100 meters, the adiabatic lapse rate mentioned above.

The release of heat by condensation as in fog formation, or possibly its absorption by evaporation of tog, has not been considered in those few mountain windflow models that consider the sensible heat balance. Extensive thermal circulations would be suppressed by fog and at any rate aerial applications would be unlikely in such conditions.

Dew fall or frost termination is quite another matter and has a profound effect on local density flows when it occurs. Nothing appears in the modeling literature on this point. If such effects were to be considered, it might be necessary to add the water vapor balance to the basic equation set.

The change in total heat content of a column of air extending to as much as 100 meters from the earth's surface in response to an average potential temperature change of as much as 10°C is small compared to typical radiation losses at the base of the column, i.e., the air near the surface has little thermal mass. The principal terms on the right-hand side of equation are the advection losses, terms which are entirely analogous to the advective terms of the mass and momentum balance.

The turbulent conduction terms are analogous to the turbulent stress forces of equation (2) and represent the transport of sensible heat by the same type of small-scale motions. They are usually divided into a flux perpendicular to the slope corresponding to the momentum flux responsible for the tangential shear stress and fluxes in the tangent plane.

The normal heat flux is generally expressed in terms of a heat transfer coefficient and the difference between the potential temperature at the terrain surface and that measured at some constant distance along the normal axis from the terrain surface; or, more generally, in terms of turbulent conductivities similiar to the turbulent viscosities mentioned above.

If local equilibrium is assumed for the temperature profiles, the heat transfer coefficients or the conductivities along the normal axis may be estimated from the surface roughness, the windspeed, and the stabilities.

For slope winds, which are uniform as described above, the turbulent conductivities have a constant ratio to the turbulent visocities in those height intervals where the Richardson number is less than about 0.1. For nonuniform flows, the situation is obscure.

The net radiation loss for the mass of air is the difference between the thermal radiation emitted by the airmass and that portion of the radiation emitted by its environment, i.e., the surrounding atmosphere and the terrain, which it absorbs. The amount of radiation emitted by the air depends upon its temperature and its water vapor content, the fraction of the radiation to which it is exposed that is absorbed depends primarily on its water vapor content.

Net radiation losses from the air, as contrasted with the losses from the slope surface have not been included in downslope flow models. The analogous assumption for engineering calculations is that the boundary layer is "optically thin."

Near sunset the air near most natural surfaces approaches a uniform potential temperature. The actual temperature decreases with height at the adiabatic rate. As the surface cools by radiation loss, the potential temperature begins to show a positive normal gradient, i.e., it increases with increasing distance along the axis perpendicular to the surface. For a uniform downslope wind caused by the pressure gradients associated with radiation cooling, the tangential shear stress will decrease with increasing distance from the slope, while the normal heat flux will not. The net effect is that the Richardson number will increase along the normal coordinate. At some time and at some distance from the slope the Richardson number will exceed the critical value of +0.2 or so. This level becomes a region of very low turbulence at which turbulent viscosities and conductivities fall to minimal values. Above this level the turbulent shear stress terms approach zero and the wind accelerates to values corresponding to a balance between the remaining terms of equation (2).

Due to an increase in windspeed above this "critical inversion", it may not persist through the night. If the velocity difference across the inversion is too high compared to the potential temperature drop, the result may be a slow oscillation with a return to a subcritical inversion.

For nonuniform slope flows, the same type of process is probably involved, but a more general expression for the turbulence production and dissipation is needed. In the case of down-valley flows, there cannot be a steady decrease of tangential shear stress with normal distance from the terrain. At some such distance the other wall of the valley is encountered.

The prediction of the position of the inversion for a particular slope and slope cooling pattern has been made with one or two exceptions on the basis of perturbation theory. In these analyses the effects of slope cooling are represented by a disturbance of the potential temperature at the surface of the slope, which is so small together with the downslope flow caused by this disturbance that products of these disturbances or their derivatives can be neglected.

Such an analysis for simple downslope flow gives an estimate of the position of the inversion that is in effect independent of time. As the surface cools further this inversion could achieve the critical Richardson number, but by that time the velocities and temperature disturbances may be too large to be considered perturbations, i.e., the calculation is no longer valid. This situation is encountered in many problems involving density flows and the physical processes involved are still obscure. The best known example is the solution for downslope flow due to Prandel. The inversion heights established a small time after the onset of cooling are sustained. The same phenomena are observed for valley flows and in relatively complex terrain.

Multiple inversions are possible in three-dimensional situations or with strongly nonuniform slopes. They can result either from overriding of adjoining density flows or local breakdowns of the inversion for a single flow, e.g., when the tilt of the slope to the horizontal increases to such an extent that the Richardson Number falls below the critical value.

The only substantial coupling between air motions above and below a critical inversion would be through pressure gradient forces and the requirements of mass continuity. If pressure gradients above the inversion are neglected, if the atmosphere above the inversion is assumed at a uniform potential temperature, if Coriolis forces are neglected, and if the air below the inversion is regarded as incompressible, the mass and momentum balance equations assume the same forms as for open channel hydraulic flow. The motion is governed by a modified Fronde number; the modification consisting of a factor formed from the ratio of the difference between the average potential temperature of the two layers to the average of the two average potential temperatures. The solutions of such equations show familiar hydraulic features such as hydraulic jumps and super or subcritical flow regimes that correspond to some observed atmospheric phenomena. These approximations are in fact the earliest model advanced for downslope winds.

If, in addition, the turbulent stress terms for the layer below the inversion are neglected, the shallow fluid equations result, which have been utilized for the estimates for inversion flows over irregular terrain by a number of studies.

A generalization of the hydraulic model has been reported that assumes a sequence of critical inversions above the terrain. These levels separate the atmosphere into material layers for which essentially separate balance equations may be written.

Boundary Conditions

The upper boundary conditions imposed on the mass and momentum balance can be loosely grouped into:

(1) a level of horizontally uniform conditions at an infinite distance above the terrain.

(2) a free surface, below a uniform region.

(3) a rigid lid.

Condition (1) is only practical for nonnumerical solutions. Free surfaces are usually employed with hydraulic type models such as those based on the shallow fluid equations.

The rigid lid is the most frequently used condition, placed well above the highest terrain feature. Conditions above the lid are generally assumed horizontally uniform and the wind at the level is usually assumed to be the geostrophic wind. Usually the lid is assumed to be a level of zero vertical velocity, although in one study it is porous allowing a horizontally uniform downdraft and placed across the top of a valley. The concept of an air shed suggests by analogy with watersheds such as boundary condition, but there obviously must be a corresponding mass outflow across the lateral boundaries.

The lower boundary poses the more difficult problem. The most common topographic input to numerical models with the exception of calculations for idealized shapes, e.g., a Gaussium mountain, or for infinite slopes, is a set of local elevations above sea level corresponding to a rectangular grid with uniform spacing. This data may be taken directly off topographic charts or in some cases is available in digitized form from the U.S. Army Map Service. Assembling an elevation grid from the maps is probably the most expensive and time-consuming task involved in using mountain wind models.

Few models operate directly on the point elevations, this data is usually smoothed either with simple four point averages or more elaborate functions with a known frequency response. These averaged heights are used as the inputs to the various finite difference calculations. The final grid spacing is typically on the order of a kilometer. In some instances nested grids are used where the mesh size is smaller in the area of greatest interest or where the topography is the most irregular.

Other surface data may include roughness lengths or drag coefficients estimated from vegetation or land use maps.

Where the heat balance is considered the lower boundary condition may be surface temperatures, net radiation at the surface, or soil heat flux. A particularly simple condition is that of an insulated dry wall together with the net radiation of the surface. In one model the basic surface temperature input is the departure of the surface potential temperature from the value estimated by the downward extrapolation of temperatures above the upper boundary.

With the exception of the infinite slope calculations and a few models that completely neglect advective terms, wind velocity components must be specified on the boundaries of the area for which the calculation is to be made. For the models using a free surface at the upper boundary, e.g., an inversion the position of this surface must also be supplied on these boundaries.

The simplest approach is to extend the calculation to the nearest natural boundary, a sea coast or a level plain, on each side; but this is rarely practical. As an alternative, some calculations represent the conditions at the boundary as the horizontal average of conditions over the area of calculation. This approach raises some questions in the case of the terrain elevation particularly if there are a few dominant features such as a large mountain or deep canyon. Other calculations replace the boundaries with an idealized level plane at the lowest elevation of the terrain in the calculation area and infer the boundary conditions from theoretical models. The use of nested grids has been mentioned above.

Cylic boundary conditions are also used where the upwind and downwind conditions are mirror images of the area of calculation. These boundary conditions have also been called no flux conditions. The same condition is imposed on the lateral, i.e., crosswind boundaries.

Approximations Compared to Field Observations

Observations of downslope and valley winds have been reported for a wide variety of sites in terms of topography and vegetative cover, although the latter is seldom reported in much detail. The sites can be roughly divided into "hilly," (grades of the order of 5 percent or less) and mountainous (grades greater than 10 percent).

Prandtl's downslope wind model suggests a decrease in H, the thickness of the cooled layer with increasing slope, but available field observations show H in the 3 to 10 meter range as compared to very deep flows often observed in mountainous terrain.

Variations in H from point-to-point at hilly sites may amount to about 25 percent over 100 meters. Potential temperature drops through the night and morning are in the 2° centigrade range with about 10 percent variation over 100 meters. Windspeeds are typically less than 2 meters per second.

In mountainous regions H may vary from a meter to 300 meters, while flow velocites may attain 5 meters per second. Variations in H can amount to 25 percent in 100 meters, while potential temperature drops can be as great as 10 degrees centigrade with a 50 percent variation in 100 meters. The inversion levels are often comparable to forest canopy heights and the flow sometimes appears to be directed by forest edges rather than the terrain fall line. Flow velocities may vary as much as 75 percent in 100 meters. In very steep terrain the inversion is discontinuous with as much as 10 percent of the terrain area remaining within a degree of the free air temperature.

All in all the field data appear to argue for:

(1) retention of the advective terms in mountainous terrain for all the balance equations.

(2) inclusion of the heat content balance in the model.

(3) retention of the tangential turbulent stress terms in the momentum balance.

There does not appear to be much support for the lid boundary condition described above.

Observations also indicate local time variations on the order of minutes on both steep and shallow slopes with amplitudes of about 30 percent of the average values for both air temperature drops and surface windspeeds.

Individual Models

The following seven wind prediction models may be said to be currently available and adaptable to three-dimensional terrain with surface cooling.

(1) Anderson's model. --This is a duct flow model and can incorporate cooling by means of a thermal plume analogy where the vertical velocity is proportional to the local deviation of potential temperature from its average over the area of calculation. Comparison with data is not reported by the author, but a sample calculation with one set of data indicates that the model cannot predict surface windspeed variation to any reasonable accuracy even in relatively shallow terrain. Results for wind direction may be better.

(2) Ball. --This is a relatively simple graphical calculation using a nomograph. The basic equations are from the earliest slopewind model. The model is adiabotic, nonadvective, hydrostatic, and uses a drag coefficient. Inversion height is an input.

(3) Fosberg and others. --This model combines Anderson's model with a solution of the horizontal vorticity balance derived from the momentum balance. The latter calculation is adiabotic, assumes a constant boundary layer height, and neglects advection. A local equilibrium is assumed. Tangential shear stress is considered, but the formulation is obscure. Fair agreement with observed wind directions is reported.

(4) Ohmstede. --This is a general material layer model. The atmosphere over the area of calculation is divided into layers separated by no flux boundaries. Solutions are for equation (1) and the mechanical energy balance as derived from equation (2). A variational method is employed known in classical mechanics as the method of Lagrange Multipliers. Turbulent stresses are not considered. The model is adiabotic and hydrostatic.

(5) Danard. --This model uses a rigid lid as the upper boundary conditions, which is identified with the mixing level. The momentum balance is evaluated in sigma coordinates, retaining advective terms and using a surface drag coefficient estimated from the deviation of the surface wind from its geostraphic value and the deviation of the surface potential temperatures from those values, which could be estimated by extrapolation from the potential temperatures and two levels above the lid. The sensible heat balance is also represented, but without radiation input. It expresses the energy difference between the final and initial states of the model. Horizontal turbulent stresses and heat fluxes are represented, but largely as devices to insure convergence of the solutions. Arbitrary values are used for the turbulent viscosities and conductivities. The model is also hydrostatic. Applications to two problems yield windspeed prediction accuracies of about ± 50 percent and wind direction errors of about 40 degrees.

(6) Ryan. --This model could be called semi-empirical insofar as it utilizes quite a number of empitical relations evaluated for the San Bernardino Mountains of southern California. A sequence of connections is made to the magnitude and direction a uniform geostrophic wind imposed over the region of calculation. The first corrected surface wind is related to the initial wind by a common planetary boundary layer model, which could be called a generalized spiral. The relation has two free parameters that are evaluated by regressions on the time of day, cloud cover, and the geostrophic windspeed.

The second correction is a vector seabreeze determined by the prevailing land-sea temperature difference with about 5 regression constants. A third vector correction is for local topographic effects involving a reduction in speed calculated from the angle to the upwind horizon and a change in direction that increases with the angle of the perpendicular to the slope downwind from the point to the average surface wind and with its downwind angle to the horizontal. The remaining additions are a slope wind and a valley wind vector corrections. The slope wind correction is based on a model for downslope winds on an infinite slope with slope cooling, i.e., it is not adiabotic but advection terms are neglected. The cooling rate is estimated from the total radiation input to the slope during the day, which in turn is estimated by regressions on cloud cover and the slope aspect. The slope wind model chosen employs a linear friction term with a coefficient more or less arbitrarily assigned. The last vector correction, the valley wind is almost completely based on the time of day, cloud cover, valley axis orientation, day of the year, and the average slope of the valley walls. The model reproduces wind directions from the original data base with an accuracy of 5 to 10 degrees for wind direction and within 50 percent for windspeed during night and mornings.

(7) Tingle and Bjorklund. --This is a hydraulic type of model assuming that the surface inversion is a free, no-flux surface. The air is assumed incompressible and the local pressure in accord with the hydrostatic assumption. The flow is adiabotic and none of the turbulence stress terms in the momentum balance are considered. Georgraphic coordinates are used so that curvature is implicity considered. The thickness of the boundary layer is assumed to be small relative to the relief of the terrain features. Horizontal smoothing introduces an arbitrary but controlled simulation of horizontal turbulent shear stress terms. The atmosphere above the inversion is considered motionless and uniform. The basic equation set has been intensively studied and their numerical solution brought to a high degree of sophistication. The model quoted has predicted the location of surface windspeed maxima and wind directions at the White Sands Missile Range in New Mexico with considerable success although numerical measures of the agreement have not been published.

(8) Scholz and Brouchaert. --This model attempts to introduce frictional drag, downslope winds and a land-to-sea breeze into the basic Anderson model.

The surface wind is represented as the sum of four potential flows: The friction drag is assumed to be proportional to the first potential flow, which vanishes at some constant height above the terrain, i.e., some mixing level, and which balances the synoptic pressure gradient. The seabreeze flow is assumed to be proportional to the average termperature difference between the coastal water and the area of calculation and vanishes at a height of 250 meters above the local smoothed terrain. The smoothing function used for this potential has a high frequency cut off of 58 kilometers. The slope flow potential is calculated from the hydrostatic relation and the assumption that the inversion is a constant height above the local terrain surface (50 meters in the calculation described). The smoothing function used on the terrain for this estimate has a high frequency cut off of 3 kilometers. The topographic component is estimated from the same smoothed terrain surface as the slope flow and the level at which the potential vanishes is taken as the inversion height. With the exception of the variable upper bound the potentials are evaluated as in the basic Anderson model. Potential temperature profiles below the inversion are effectively assumed linear. For the problem discussed, the surface wind field near a shoreline, the estimates based on empirical fits of the fire constants, and filter parameters involved, compared with about nine surface stations, show an accuracy of about $\pm 50^{\circ}$ for direction and about ±50 percent for speed, with no apparent bias for the latter.

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FOREST WIND

The surface wind input to the forest spray behavior models found in the literature is relatively modest, consisting of average speeds and directions for at the most two height intervals, some measure of the turbulence intensity, or equivalent and an entrainment coefficient.

The calculations of interception efficiencies in theory requires a great deal more information about the shape and size of the wakes behind branches and crowns than is available, but this lack has not been generally noticed because of the many other questions involved in spray behavior.

Future spray models will probably be more demanding, requiring continuous profiles of velocity components through the canopy and an effective diffusivity for calculating the rate of transport of spray drops by turbulent motions in the canopy.

The variation of windspeed with height above a forest canopy is usually expressed in terms of the "displaced law of the wall." This can be stated roughly as:

$$\left(\frac{\text{windspeed}}{\text{friction velocity}}\right) = \left(\frac{\text{log function of displaced height}}{\text{roughness length}}\right) + (\text{stability factor}) \times (\text{displaced height}) \quad (4)$$

The friction velocity is the ratio of the square root of the surface drag force, i.e., the tangential turbulent stress to the air density.

The displaced height is the actual height at which the windspeed is measured minus a length called the "displacement height."

The roughness length is the second aerodynamic parameter for the canopy, generally smaller than the displacement height.

The stability factor is a function of the Richardson number above the canopy in a very general sense. It may be rigorously defined for the situation where the displacement height is zero, e.g., over a rough sand surface. But its form for a forest surface is complicated by the consideration that the sources and sinks for heat and momentum may not have the same vertical distribution. This would be particularly true for the times of day with low solar altitudes such as in the early morning. In any event, if the Richardson number over some interval of height above the tree tops is close to zero, the last term in equation (4) vanishes.

The lower limit of the height interval for which equation (1) is valid is also in some doubt. Some studies show reasonable conformity right down to the tree tops while others suggest a lower limit of about twelve times the roughness height above the displacement height. The interpretation of profile measurements is speculative near the tree tops because of the local variations from point-to-point in the stand. At these levels the equation (4) must refer to an average speed in the horizontal plane.

The rate of spread of a spray cloud released over a canopy of nearly neutral stabilities can be theoretically estimated from the ratio of the difference between the height of release and the displacement height to the roughness length.

Estimates of the displacement height and roughness length from canopy structure are still suprisingly speculative in view of the increasing number of above canopy windspeed profiles found in the literature.

An obvious question is whether both or either parameter varies with the windspeed over the canopy for a particular forest stand. The studies encountered are in substantial disagreement on this point. Some report constant displacement height values and an increase in roughness length with windspeed, others show the constant displacement heights with a steady decrease in roughness with increasing speed, or a decrease to a minimum with subsequent increase. Variation of both lengths have been observed with the suggestion that their sum remains relatively constant.

The weight of the results seem to suggest that the roughness length decreases with increasing speeds at very low speeds and at very high speeds. The first effect is due to a changing wake pattern around the foliage elements and the second is due to deformation of the crowns.

If it is assumed that for some particular range of windspeed over the canopy, both lengths are constant. About five formulas are available in the literature for estimating their values. The most common assumption in the literature is that both are some fraction of the average tree height. Others are that the roughness length is a fraction of the difference between the average tree height and a factor which may be the Leaf Area Index or the horizontally projected crown area.

The displacement height has been found to approximate the height of the level of maximum foliage concentration where there is such a clear maximum for pine or Douglas fir stands at about the midcrown height. Since so many of the wind profile studies are made for practical reasons over stands in the 10 to 15 meters height range and with about the same leaf area index, it is difficult to discriminate between these estimates.

There are considerably fewer measurements of windspeed in the canopy. In general, all vertical windspeed profiles show a steady increase with height above the displacement height. Where there is also a clear foliage concentration maximum above the forest floor, there is a tendency to show a level of minimum speeds at that maximum. Some arguments may be advanced for similarity of the profiles above the displacement height between different conifer stands when the displaced heights are scaled by the roughness length. But there is little agreement on the nature of the airflow below the displacement height.

Many of the earlier studies report changes in the shape of the vertical profile of windspeed with changing speeds over the canopy. The interpretation of these results is obscured by the probability of horizontal variations in the windspeed profile whose distribution relative to any one point would change with wind direction changes.

Later reports do not indicate such changes and suggest that for a given wind direction over the canopy the windspeed at any point in the canopy is a relatively invariant fraction of the friction velocity over the canopy and for neutral stabilities, of the windspeed at a particular level over the canopy. The choice between these two velocity scales becomes relevant when the effects of temperature stratification on the canopy profile are considered. For stable conditions one would anticipate lower speeds, speeds relative to the tree top speed, but very possible the same speed ratio to the friction velocity, an effect which may explain the variations in relative subcanopy space speeds with above canopy stability noted by some observers.

Changes in profile shape may also occur because of canopy deformation, but this is unlikely for the conditions encountered during spray operations.

There are few canopy windspeed measurements made with above canopy speeds in the 0.5 mps and below range where density flows, i.e., downslope winds, were not in progress. In this speed range the airflow pattern around individual elements of the canopy and the resulting drag forces change rapidly with windspeed.

Canopy turbulence has been measured in a few field studies and in the wind tunnel over simulated forest stands.

The studies indicate a maximum in the energy of the vertical turbulent motions just above or just below the top of the canopy. This has important implications for the use of so called reflection coefficients in plume spray models. There is no relative decrease in the mixing efficiency as the canopy top is approached, unlike the situation near a solid wall.

The turbulence over the canopy has been shown to correlate well with the Richardson number much as is the case over impermeable surfaces.

The distribution of turbulent energy between the various sizes of eddys; called the turbulent energy spectrum shows local maxima in the canopy as contrasted with normal boundary layers over open terrain where the energy decreases with decreasing eddy size, the shortness of the records, and the variety of instruments used raises some doubts as to their significance. But if these local maxima are real, they imply two scales on which the energy of the average large scale motion is converted into turbulence.

There may be appreciable wind direction changes with height through a forest canopy due to the tendency for the wind over the canopy to have an appreciable angle to the synoptic pressure gradient. This effect might amount to as much as 20 degrees, depending on the cloud cover, geostrophic speed, and the stand roughness.

In conclusion, there are at present no theoretical models of canopy flow available that would allow the vertical wind profile on the diffusivity to be predicted from above canopy conditions and forest inventory data. Such models are approaching practicality, however, and will probably emerge in the next decade.

TECHNOLOGY TRANSFER

Introduction

Technology transfer is defined as the process by which discovery of knowledge and development of new equipment is put into application in the field. The gap between the knowledge and application is identified as the technology transfer problem. Frequent complaints in the field about inadequate equipment and methods and researchers allegations of lack of use of available equipment and methods suggests technology transfer problems.

Aerial application requires a large variety of diverse skills among which are administrative, biological, and physical sciences skills. The administrative skills are common with many other projects and therefore these will not be specifically discussed here. The administrative constraints, however, may result in technical problems.

Technical Knowledge

Aerial application of pesticides utilizes a variety of skills from the physical sciences to cause beneficial changes in the biological environment. The project manager and his staff most likely are trained biologists who have shown ability in administrative supervision. Most biologists tend to be weak in the basic physical sciences, such as physics, chemistry, engineering, aerodynamics, and meteorology.

On small projects, the project manager is expected to be the most informed person on technical matters. He is expected to be well trained in the physical science skills as well as biology. However, the only way he is likely to have the physical science skills is through past experience and training. Lack of minimum requirements for project personnel does not assure the forest manager that the aerial application projects have technically adequate supervision.

Large projects are more likely to include personnel with previous experience. However, the Forest Service Manual indicates no systematic method that would insure that this be so, or what specific skills are required. Again, the project staff is likely to consist of trained biologists with sparce knowledge of physical sciences. The latter usually is covered by following guidelines and requirements of previous projects.

Knowledge and Application of Biology

The biological training of project personnel assures that most of the available knowledge is understood and applied in a proper way. New knowledge usually is transferred through technical journals that the biologists read. As indicated by the problem analysis outline, biology is not indicated as a major problem. Availability of the technical references may be the major technology problem. Libraries are not very extensive in field offices and Ranger Districts.

Knowledge and Application of Physical Science Skills

Because the biologists generally do not have extensive backgrounds in physical sciences, they are not familiar with the technical literature, and probably are not able to understand the information when it is provided. Methods and equipment developed and used by physical scientists may be transferred into application without adequate understanding when they are proper and when they are not likely to provide desired results. These methods and constraints may be followed for a long time, even when changes in methods of application have made the earlier assumptions obsolete. For example, assumptions about the spray cloud, its transport, and deposit measurements were developed in the 1950's when the application rates were 1 gallon per acre, desirable spray deposit above 100 micrometers, and the aircraft flew at 100 mph. Yet, the same assumptions are used today, when we apply one-fourth of the volume, try to achieve spray droplets with diameters of less than 50 micrometers with aircraft that fly near 200 mph. Now the fieldman complains that the spray is not going where he expects it; the spray cards are not telling him what kind of coverage is achieved; and navigation equipment is not adequate.

There is a large amount of knowledge that is not being utilized in the field. Greater participation by scientists with knowledge about spray droplets, meteorology, and other physical sciences would increase efficacy of materials used, safety in the environment, and greater chances of hitting the target pest.

References of Aerial Application Technology

Past control plans probably are the most commonly used reference material in planning of aerial application projects. As a result, new methods and skills are not likely to be introduced unless the project manager has sufficient experience to recognize the need for improvements and has the time to search for it. Reference libraries are usually available at the larger project headquarters, but rarely available in the field. Physical sciences literature is available only to the research centers near universities. The only available reference to project planning and management is Aerial Application of Agricultural Chemicals, USDA Handbook 287, published in 1965. It is not widely used by the Forest Service.

Specific guides are available as how to's on some specific tasks necessary on a spray project. Many of these are recent products of Methods Application Group efforts. Technical articles on specific aspects of aerial application are abundant, but very scattered in a large variety of publications. Centeralized reference materials or expertise is not available to the project managers.

A variety of skills used by the field manager and his staff have never been published. Field improvements are made by experienced people and applied for many years before others become aware of them. The primary source of information on changes in equipment and methodology of spray delivery are acquired in the field from contractors and chemical company representatives.

INSECTICIDE SPRAYING

The first aerial application of insecticide in the United States took place in 1921. A Curtis JN6 biplane sprayed lead arsenic to control the catalpa sphinx moth.

The first record of forest spraying by aircraft occurred in Louisiana a year later. Until the mid-forties, aerial application was expensive with few successes.

But DDT ushered in a new era in aerial spraying after World War II. DDT proved effective and inexpensive and relatively easy to apply. It quickly became the primary agent for controlling forest insects.

A wide range of World War II aircraft sprayed DDT, effectively controlling gypsy moth, tussock moth, spruce budworm, and other defoliators. DDT consistently yielded mortalities greater than 95 percent of the population when applied at the rate of 1 pound per gallon of fuel oil per acre. Naturally, attention was given to release height, application rate, swath width, nozzle size, timing of application relative to larval development, meteorology, and drop size. But the persistent nature of DDT allowed maximum flexibility in application.

But the environmental awareness of the sixties forced a reexamination of DDT's impact. Although relatively little DDT was applied to forests, the Forest Service decided to restrict the chemical's use on National Forest lands in 1964. This was followed by a general ban in 1972, except for special emergency use. A special use permit, however, was granted in 1974 to use DDT against the tussock moth, which was threatening high-value stands of Douglas-fir in the Northwest. DDT was the only insecticide known to be effective for tussock moth control.

Because DDT had proven so effective in controlling forest defoliators, research and development efforts had long since shifted to other insects and crops. The restrictions on DDT imposed in 1964 left the Forest Service with no effective chemicals that were environmentally acceptable. That same year the Forest Service established a research group at Berkeley, Calif., to develop selective, short-lived chemical treatments for controlling forest insects.

Several chemicals looked favorable in the laboratory and in the field, but when tried on a pilot basis and applied in the same manner as DDT, they often proved ineffective in controlling insect pests. Had we achieved control with DDT due to excessively high application rates and its persistent nature? Or were other factors involved? Since we were using the same aircraft and techniques to apply these new chemicals, we concluded that it was appropriate to research and develop more efficient methods for delivering the chemical to the target for immediate results. With the less persistent chemicals we could no longer count on delayed results.

Failures in the use of insecticide, many of which could be attributed to poor application, has resulted in the loss of some insecticides to forestry uses, and the discouragement in the registration and use of others.

HERBICIDE SPRAYING

Aerial application of herbicides in the National Forests has been an outgrowth of the development of the phenoxy herbicides and helicopter aircraft. Although other herbicides have been applied and fixed-wing aircraft used before helicopters became available, the phenoxies, applied from helicopters are the source of almost all aerial herbicide operations on the National Forests.

Chemists had discovered phenoxy herbicides and knew of their plant control potential but this knowledge was not published until 1945. In 1949, 10,000 tons of 2,4-D were manufactured in the U.S. alone.

The Forest Service began field experiments and tests using aircraft and 2,4-D and 2,4,5-T in the late 1940's and early 1950's. These earliest applications were primarily in rangeland where it was shown that these chemicals aerially applied, could control undesirable brush and weeds, improving forage production.

Fixed-wing aircraft require open gentle terrain for flight safety at low altitudes. Because accurate placement of sprayed materials requires low-level passes, aerial applications in rough, tree-covered terrain had to await the development of the helicopter. In March 1946, The Civil Aeronautics Administration issued its first commercial license for a helicopter, Bell's two-place model 47.

In 1959 flight restrictions for fixed-wing aircraft made it necessary for the Beaverhead National Forest in Montana to choose the helicopter--previously considered too expensive--to continue its range improvement work using herbicides.

In 1962 the Forest Service's Range Seeding Equipment Committee reported that helicopters were available in most parts of the country and were becoming competitive with each other as well as with fixed-wing aircraft. The Committee's 1960 report shows 27,350 acres of rangeland treated with 2,4-D by fixed-wing aircraft and 12,882 acres by helicopter, mostly in the Forest Service Northern, Rocky Mountain, Intermountain, and Pacific Northwest Regions.

Between 1952 and 1967 through research and operational applications, the Siskiyou National Forest in Oregon applied phenoxies to 34,000 acres for conifer release. The program called for treatment of approximately 15,000 acres per year, 99 percent applied by helicopter.

These are but a few specific instances of use of aerially applied herbicides in the National Forests. They do show that herbicides, primarily the phenoxy-acetic acids, have been aerially applied in the National Forests for nearly 30 year. Range improvement, conifer release, plantation site preparation, and brush control for fuel management have been the purposes for which the largest acreages have been treated.

Throughout the years methods of monitoring herbicide efficacy, and its effects on forest ecosystems have been developed and used by research and applied to field operations.

From the beginning, Forest officers have worked closely with State game department personnel planning plant control projects to help assure protection and improvement of fish and wildlife habitat where herbicides have been used.

FOREST SERVICE

. Managed Forest Watersheds - Douglas-fir Region (PNW1602)

Currently studying herbicide residues in air, both as particulates and volatiles to determine the loss of aerially applied materials to the atmosphere. Relevant to offsite movement of pesticides and human exposure levels.

Use of rare earth tracers to fingerprint spray solutions. Being developed as a tool to help either in research or in operational programs to uniquely identify specific batches of spray material.

Herbicide spray deposit assessment. Use of mylar cards and filter discs to determine initial levels of herbicide entry into the target area.

. Reforestation Systems in the Pacific Northwest (PNW-1201)

No studies currently underway but have been involved in the past in two areas:

--Drift control through use of equipment, formulation of additives, etc.

--Testing new delivery system.

. University of Maine (John Dimond and Thomas Christensen)

Conducting state-of-the-art survey of aerial applications to eastern forests. In conjunction with field experiments of efficacy have compiled data on nozzle and aircraft performance.

. Insect Pathology and Microbial Control (Northeastern Forest and Range Experiment Station)

Working in the area of formulation and nozzle interactions to achieve maximum deposition with an effective droplet spectrum.

. Field Evaluation of Chemical Insecticides (Pacific Southwest Forest and Range Experiment Station

In cooperation with Malcolm Furniss, developing an aircraft delivery system of pheromone impregnated plastic capsules.

Laboratory tests are being conducted on methods for determining spray deposit and interpreting the significance of results obtained with various methods, i.e., Kromekote cards, GLC, salt tracers, aluminum plates, and mylar plates. Tests are being conducted jointly with FIDM/MAG.

In contact with various representatives from private industry that are marketing or will market guidance systems. Developing study plans to test and evaluate the various systems.

. Fire Fundamentals Project (F. Albini, IMS-NFFL)

Albini is working on a forest canopy flow model to supply a wind input to fire spread models. His approach to date consists of equating the above canopy drag forces to those on the foliage elements. Above canopy drag coefficients are taken from correlations with tree height found in the literature.

. Forest and Mountain Meteorology Project (J. Bergen, RMS)

A canopy flow model is being assembled to be compared with observations made at Foxpark. The approach attempts to consider small scale horizontal advection explicitly.

Data analysis is partly done on airflow patterns in the larger of two clearings at Foxpark.

Turbulence data from Gnat Flats (WA) is being compared with the assumption of proportionality of turbulence intensity and friction velocity.

Cooperative measurements are being planned with Smoke Management Group at Fort Apache, Ariz., in the fall of 1978. Temperature drops, air velocities, and net radiation will be measured along a cross-section volume of the canyon together with the inversion height as determined by the acoustic sounder. Analysis will be directed toward the relationship between the down-canyon flow and the contributing slope winds.

. Multiresource Planning Project (P. Ffolliet, RMS and University of Arizona).

P. Ffolliet and B. McCade are analyzing the results of radiometer and sky camera observations at two mountain sites with the eventual purpose of developing a method of estimating the change in low cloud cover along a trajectory.

. Field Evaluation of Chemical Insecticides (G. Markin, PSW)

G. Markin is currently analyzing pesticide drift deposits made with balloon-supported cords in a mountain valley during drainage conditions. The results are complex but show transport well beyond the 20 km range.

. Forest and Mountain Meteorology Project (M. Fosberg, RMS)

M. Fosberg is currently collaborating in a study of mesoscale circulation models, including density circulations relative to a data base in northwestern Oregon.

. National Fuel Inventory and Appraisal Systems (S. Hirsch, RMS)

Efforts made to establish the respresentativeness of fire index studies have included some attention to the effect of stacking density on the vertical wind profile. Some use was made of published data.

. Smoke Management R&D Program (C. Tangren, SE-SFFL)

Among other problems, the movement of smoke by down-valley winds in the area of prescribed burns is being studied. A field study of such flow is scheduled in fall of 1978 near Fort Apache, Ariz., in cooperation with the RM Station, the Arizona Air Quality Bureau, and the BIA.

Modeling has involved variants of plume models with buoyancy corrections. The problems have many points of similarity with the application of tilted plume models used for spray applications.

. Northeast & Southwest Areas of State and Private Forestry

No research or systematic investigations to improve or develop new methods of aerial application of pesticides was reported. However, new technologies evolve on major spray projects because of necessity.

--Navigation. Three new navigational systems have been examined or tried on the Maine cooperative spruce budworm control project. Large spray blocks, over 10,000 acres, require block and swath marking within the aircraft. In 1976 and 1977, an inertial guidance system developed by Litton Industries was used. In general it performed satisfactorily.

The navigation system used in Maine in 1978 was developed by Globe Navigation. It utilizes seven Omega signal stations around the world used by ships and aircraft.

A trispondent system developed by Del Norte for Ag aircraft was evaluated at Fredericton, New Brunswick, by Forest Protection, Ltd.

Because these navigation systems are useful for a wide variety of aerial work, such as aerial detection surveys, spraying, and search and rescue, some governmental agency evaluation may be useful to determine their accuracies and variety of potential uses.

--Nozzles. Open nozzles or pipes to distribute insecticides occasionally have been used in Canada and in the United States. An opportunity presented itself when Maine requested the State and Private Forestry technical staff to determine the characteristics of spray deposit for DC-4's, PV-2's, and TBM's. Simply, the spray system utilizes the standard boom and nozzles, except that the nozzle cap and orifice are removed. The spray flows at lower tank pressures and the airflow over the 1/2-inch-wide nozzle tip provides shearing and break up of the liquid. Field evaluations of the spray patterns appeared to be similar to earlier observed flat fan nozzle tips. The major advantage is the reduced opportunity for clogging of nozzles.

. FI&DM/Methods Application Group

Demonstration of Turbo-Thrush aircraft capability to spray in complex mountainous terrain. Field trials conducted during July and August 1978.

Chacterization of B.t. and Sevin 4-Oil spray from Marsh Turbo Thrush. Trial completed report in progress.

Characterization of oil spray from C-52, PV-2, and TBM spraying with TeeJet nozzles with no pipes. Results reported in trip report.

Contract study to investigate the relationship between volume median diameter and number of spray droplets to mass or volume. Report in draft form.

. FI&DM/Northern Region (R-1)

Night spraying demonstration with night flying goggles in North Dakota during May 1978. Fixed-wing aircraft applying B.t. to cankerworm in shelterbelts.

. FI&DM/Southwestern Region (R-3)

Tussock moth virus will be applied on a pilot project at Los Alamos, N. Mex. Application will be by helicopter.

. FI&DM/Missoula Equipment Development Center

-- Spray Deposit Assessment Systems. The objective is to develop a quantitative system for spray deposit assessment on pilot and operational spray projects. There are four general methods for assessing spray deposits: physical, chemical, biological, and optical. Capability to assess spray deposit is needed for several reasons. How much insecticide reaches the target area must be known, and spray drift in nontarget areas is becoming critical. An immediate check within the target areas will reduce missed spots and swath overlaps. Entomologists need this information to develop correlations of spray deposit and insect mortality in the spray areas.

-- Remote Meteorological Monitoring for Spray Blocks. The objective is an operational system for remote meteorological monitoring of spray blocks prior to, during, and after the actual aircraft spray flight. As a result of the pilot testing program in the western United States, a need has been recognized to have real-time meteorological information available for spray blocks. A key factor in achieving desired insect mortality is the behavior of the spray as it is disseminated from the aircraft. Spray behavior is greatly affected by meteorological conditions. By knowing precisely what the conditions are on a spray block, predictions can be made as to spray behavior. Current methods for monitoring meteorological information have several disadvantages. At present, someone has to be in the spray block to collect the data. Several people are needed if data are to be collected from more than one station in the spray blocks. Spraying would be more effective and much more efficient if this data could be relayed remotely to the airport or base camp prior to deployment of spray aircraft.

-- Optimum Size Spray Droplets. The objective is to increase the efficiency and effectiveness of controlling forest insects with aerial sprays by determining the optimum spray droplet size for varying situations so that this data can be incorporated into application equipment requirements. It is increasingly apparent that spray drop size has much to do with the success or failure of an aerial insecticide application. Factors such as settling and evaporation rates are influenced by drop size. By knowing the optimum drop size, spray equipment can be modified to produce that needed size. For example, in the case of microbials, where the target is the foliage the insect feeds on, the drop size may need to be different than when the target is the insect.

-- Rotary Versus Fixed-Wing Spray Aircraft. The objective is to reduce the cost and increase the effectiveness of aerial spraying by providing information and recommendations concerning rotary and fixed-wing spray aircraft performance. There is a need to establish criteria for selecting aircraft best suited for doing a specific spray job. The current trend in the Western United States is for spray project managers to use helicopters exclusively for the application of insecticides. The belief that helicopters are able to apply insecticides more accurately than fixed-wing aircraft is not based on hard data. Exclusive use of helicopters can increase cost-per-acre two or three times over that of fixed-wing aircraft.

-- Characterization of Small Spray Aircraft. The objective is to apply known characterization techniques to develop and make available a procedure for use on pilot or operational projects that will enable the project entomologist to characterize the aircraft in 2 hours or less. Most aerial application of forest pesticides is done by contract aircraft. The project entomologist can specify application rates and spray characteristics such as volume median diameter. It is usually necessary for the contractor to make minor changes to his spray system to achieve the desired spray characteristics. Changes may include nozzle type, size, or orientation or aircraft speed or height. To verify that the contract aircraft is producing spray having the specified characteristics, the project entomologist needs a rapid quantitative method of measuring spray characteristics. Present methods are primarily subjective or require several days to obtain quantitative information.

. Douglas-fir Tussock Moth (DFTM)

This program sponsored a few studies involving aerial application. Three studies in particular were significant in that they were pioneering in nature, and a systems engineering approach provided a basis for future modeling of spray behavior:

- Combining and validating the Grim/Barry canopy penetration model and Cramer dispersion-deposition model. Report submitted to DFTM. This is the first model of this type.

- Spray behavior, droplet impaction, and optimum drop size study conducted under controlled conditions in a wind tunnel. Report submitted to DFTM.

- Spray nozzle, flat fan, and Beecomist characterization in wind tunnel. Report submitted to DFTM.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

In 1977, a comprehensive, long-range research program plan was developed to address research needs in many problem areas identified by the industry.

Due to budget restrictions, the scope of the planned program was narrowed to address a few of the most critical industry problems. Within the restricted budget, a significant amount of research in the selected areas can be conducted.

Although current activities primarily center on fixed-wing agricultural aircraft, it is recognized that rotary-wing aircraft make up a significant and growing portion of the industry. While no specific activities with helicopters are planned as part of current NASA research, future rotary-wing research activities could evolve. The current NASA aerial applications research program is concentrated in the following five areas:

1. Wake Interactions for Reduced Drift. - Research is being conducted seeking reduced drift of chemicals away from target areas. Drift is the most important concern of the U.S. industry. In fact, drift has been identfied as a high-priority problem in other parts of the world, including Warsaw Pact as well as Western nations. All active ingredient that does not contribute to killing the target organism not only represents pollution, but also represents direct economic loss as well. Drift is seen as a complex problem requiring an understanding of the interplay of the spray behavior, wake aerodynamics, and economic, meteorological, and biological factors involved in aerial application of agricultural chemicals. A satisfactory solution to the drift problem will require contributions from the above disciplines.

2. Aircraft Aerodynamics. - Improvements are being sought in aircraft performance. Improved fuel efficiency, aircraft productivity, and safety are the objectives of these improvements. A special area of interest is the high angle of attack performance, stability and control, and handling qualities. In many operations, these aircraft spend as much as 30 percent of total mission time in turns, where airspeeds are within a few miles per hour of stall speed. Good turning performance depends on minimized drag under these conditions. And a high level of safety depends on minimized tendency for wing-drop or roll-off at the stall. Recently, a NASA General Aviation Stall/Spin research program has demonstrated that certain high lift devices mounted on the wing leading edge exhibit the potential for inhibiting wing-drop or roll-off at the stall. Such devices may have significant early applications to agricultural airplanes in which stall/spin/spiral/and mush-type accidents account for one-half of all accident fatalities.

3. Swath Guidance Systems. - Current electronic swath guidance systems appear to provide the signal accuracy required (roughly 1 for row crop agricultural aviation missions. Conventional course deviation indicator (CDI) displays, which are used to provide the pilot with raw data for steering information, appear inadequate for certain operating conditions. The primary goal of NASA research on this topic is the development of low-cost, highly reliable methods of providing steering information to the pilot. To date, the extent of NASA work in this area has been to demonstrate a radar-laser position-tracking flight-test technique for documenting the closed-loop accuracy of swath guidance avionics systems. Future research can use this capability in addition to piloted, ground-based flight simulators for displays research.

4. Dispersal System Technology. - Research on dispersal systems will be conducted with wind tunnels and in flight tests seeking to improve pattern uniformity and width. In addition, reductions in dispersal system power requirements will be sought. Aerial applications industry interest is very high in expanding the performance envelopes of dry material spreaders. This interest has been sparked by the excess power currently available in the larger, turbine-powered and the high-horsepower reciprocating-powered agricultural airplanes. Research is planned to make the best possible use of this excess power in current airplanes for spreading fertilizer, for example, at rates possible as high as 400 pounds per acre on swath widths as high as 80 feet for some application rates, and at speeds as high as 120 mph for certain missions. The immediate beneficiary of such technology would be the rice industry, users of a vast majority of aerially applied fertilizer. In the long range, however, this technology may permit expansion of aerial fertilizing operations into other markets.

5. Field Calibration System Technology. - Each available spray accountancy technique suffers some shortcoming incapability. New calibration techniques, such as laser doppler velocimetry, laser fluorosensing, bio-detection, and others offer potential for improved capability in documenting drift and deposition of aerially applied agricultural chemicals. The role of NASA research in this area is to evaluate alternative spray accountancy techniques and to document their value for use by the aerial applications industry. It would then be the responsibility of the research community at large to establish standards for the use of new techniques.

The past 2 years of aerial applications program activities at NASA have produced a well-developed data base on the agricultural aviation industry, its aircraft, missions, problems, and technology needs. These activities have also produced valuable research tools and techniques for use in providing technology to the industry. In ideal terms, the goals of current NASA work can be stated as follows:

--Reduce drift.

--Improve spray pattern uniformity.

--Reduce turn time.

--Improve cruise efficiency.

--Improve takeoff performance.

--Improve stall safety.

--Improve swath guidance accuracy.

--Expand dry dispersal system performance.

--Improve spray accountancy techniques.

Some of the tools being applied toward these specific program goals are described below:

Vortex Research Facility. - In the Langley Vortex Research Facility methods have been developed for the use of small scale models of agricultural airplanes for studying the interaction between the airplane wake and dispersed materials. Scaling laws have been developed for using small glass or polystyrene beads, dispersed from the scale model airplane, which behave like real liquid or dry particles dispersed from real airplanes. To complement these empirical techniques, computational tools are being developed to predict particle trajectories in the wake and deposition on the ground. While these techniques do not provide complete answers by themselves, they do provide control over many of the variables (meteorology for example) that make full-scale testing so difficult. In the long run, time and money can be saved by such research procedures. Both the scale model and computer techniques will be used to seek methods for reducing drift, increasing swath width, and improving pattern uniformity of current and advanced aircraft configurations.

Full-Scale Tunnel. - As part of an effort to construct a data base on present-day agricultural aircraft and dispersal equipment, an Ayres Thrush S2-R-800 was recently tested in the Langley full-scale (30 by 60 feet) wind tunnel. Following baseline, unmodified airplane tests, several changes were made to study the effects of drag-reduction devices, leading-edge high-lift devices, a turbine engine modification, and wake modification devices. A laser spectrometer system was used to measure droplet size distributions in situ, in the near-field wake at flight speeds, for a sampling of liquid spray nozzles and rotary atomizers. Wind tunnel tests of this nature fill the need for aerodynamics, stability and control, and near-field wake data.

Flight Test. - Where the vortex facility tests provide far-field wake data and the wind tunnel provides near-field wake data, flight testing provides real-world validation of these previous tests. Flight validation is the final step in the analysis of any wake modification technology developed. Flight testing also provides a thorough analysis of the effects of any aircraft modifications on performance and handling qualities. Flight testing of the Thrush, which was tested in the full-scale tunnel, is planned to begin during 1979. Many of the drag cleanup, high-lift, and wake modification devices developed in the tunnel will be evaluated in flight. This airplane can also serve as a platform for evaluating new displays for swath guidance systems.

AERIAL APPLICATIONS RESEARCH IN CANADA - 1978

- Spruce Budworm Pheromone Trials, Nova Scotia & New Brunswick (C.A. Miller)

Dr. Miller is the coordinator of a program to determine optimum application rate and effectiveness of the Conrel fiber formulation of spruce budworm sex attractant. The trials involve aerial application of the fiber on four 100-acre plots in New Brunswick and Nova Scotia.

- Development of New, Low-Dray Spray Boom for DC-6B (R.H. Wickens and Conair Aviation Ltd.)

A new, low-drag spray boom for the DC-6B aircraft was developed as a joint project of Conair Aviation Ltd. and Dr. R.H. Wickens of Low Speed Aero-dynamics Laboratory of the National Aeronautical Establishment. The new boom reduces the effective horsepower loss due to drag from 800 horsepower for current state-of-the-art booms to 150 horsepower for the new, low-drag configuration.

- Improved Pesticide Flow Control System for Spray Aircraft Conair Aviation Ltd.)

Conair has developed a flow control system for spray aircraft that uses ground speed inputs to modulate pesticide flow rate. The system is reported to guarantee spray emission rates of within plus or minus 1 percent of the required rate for a desired application rate.

Currently, the company is also developing improved helicopter systems for applying granular fertilizers to forest lands.

- FPMI Helicopter Experimental Spray System (J.C. Edwards)

Work continued on the program begun in 1977 involving the development and testing of a helicopter-specific aerial spray system for forestry, plus related application techniques and evaluation of helicopter-compatible emission devices. Field calibration trials were conducted near Leitrim, Ontario, using Beecomist Model 350 spray heads on a Hughes Model 500C helicopter and deposit was sampled near ground level in the open and under the canopy as well as within the canopy at mid-crown.

- Investigation of Droplet Characteristics and Behavior (J.J.C. Picot)

Dr. Picot's work involves the characterization of the droplet spectra emitted by various nozzle types, including the Beecomist, TeeVet, and Micronair. Much of the work was conducted in the National Research Council wind tunnel at Ottawa and made use of both photographic techniques and an electronic probe device.

He has also developed a model to investigate the various influences and their effects on a droplet between its emissions and impingement.

In addition, Dr. Picot has conducted investigations of the wake of the TBM Avenger. This involved the emission of dye from nozzles at the wingtips of the aircraft, and the use of photographic techniques from a tower at canopy height as the aircraft flew past.

-Investigations of the Timing of Spray Agains Spruce Budworm (J.R. Blais and R.F. DeBoo)

This program was conducted in Quebec and is reported to have involved a comparison of the results of spraying second and third instar larvae versus third and fourth.

UNIVERSITIES

Some university research was identified through personal contacts of task force members. To supplement this information a search of Current Research Information Services (CRIS) was ordered under the title pesticides/ Aerial application. More than 100 abstracts of individual projects were retrieved. Most of the projects were not specifically directed to forest and range but many were relevant in some way.

Rather then reprint the CRIS abstracts here, the reader may obtain a current copy from:

Current Research Information Service
Cooperative State Research Services
South Agricultural Bldg., Room 6818
14th and Independence Ave., S.W.
Washington, D.C. 20250

OTHERS

. S. Rao, of the Atmospheric Turbulence and Diffusion Laboratory, NOAA at Oakridge, is devising a canopy flow and transport model based on second order closure and Lumleys local time scale, i.e., the ratio of turbulence energy to dissipation.

. B. Hutchinson and D. Matt of the same lab are instrumenting a forest site to measure the horizontal variation of turbulence spectra and velocities at a number of levels, including within crowns. This will be the first attempt at such a survey.

. D. Miller, University of Connecticut at Storrs, is analyzing velocity profiles made during cold-air flow on a hill in different vegetation types.

. S. Barr, of the University of California Lab at Los Alamos, is currently studying the flow of air along a forested canyon using isotope tracers.

. C. Murphy of the Savannah River Laboratory, DOE, is currently engaged in modeling gaseous diffusion through forest canopy.

Forestation Notes

Forest Service · USDA
Pacific Northwest Region
State and Private Forestry

No. 56 March 1979

This is for people interested in planting and growing forest trees

Post Office Box 3623
Portland, Oregon 97208

Frank A. Ter Bush
Reforestation Specialist
State and Private Forestery, Region 6

REFORESTATION REFLECTIONS

Do you remember the early days of the NASA program? Public interest would raise to a fever pitch. The great day would come. The countdown! ---4,3,2,1!! Ignition! Blastoff! There would be a tremendous burst of flame. Nothing would happen! The launch would abort!

The investigation would show that some minor part of a system had failed. The engineers would go back to the drawing board. They would come up with back-up systems and stronger parts.

Not so with reforestation-we don't have teams of PH.D's and armies of technicians to explore our failures. Frequently, the forester never learns why he succeeds one place and fails the next. Dealing with living material poses problems that make satellite launches seem like child's play. In addition to this difficulty, the government doesn't provide the forester unlimited funds for the job. It has to be done right the first time. If it fails, who knows when there will be time or funds to come back for a second or third try.

A successful reforestation effort is more complex than a satellite launch. Every part of the procedure must be carried out with a high degree of accuracy. Mother Nature seldom forgives sloppy work. The results are written large on the landscape.

The following reviews some of the things that can determine whether reforestation will be a success or a failure.

PLANNING--Planning and plantation success go hand in hand. Regeneration decisions begin when the harvest method is chosen. Perhaps three to four years before the first seedling is planted, the proposed plantation must be given careful thought. The climate, topography, soil, vegetation, access, and potential problems must be studied and a plan of action prepared that insures that the seedlings are tailored to the site. Unless this is skillfully done, all subsequent work may be time, money, and effort wasted.

SEED--Successful farmers insist on the finest seed available. The best seed can increase yield substantially. Seed is even more critical to the Northwestern forester. The seed must be pure, vigorous, and, above all, native to the site

where it will be used. Stands developed from off-site seed may grow vigorously for 10 to several dozen years only to fail long after the initial seed lot selection decision was made.

SEEDLINGS--The nursery is responsible for producing site specific seedlings. Plantation success hinges on coordination and cooperation between field and nursery. The nurseryman needs plenty of "leadtime" to insure production of the proper product.

SITE PREPARATION--No farmer would waste seed on poorly prepared land, foresters cannot afford this either. With forethought and good management, his crop will occupy the site for 50 to 100 years. Proper "site prep" is essential.

PLANTING--Scrupulous attention to the myriad of details is essential to success. Crew training and supervision, seedling handling and placement all must be correct in every particular.

FOLLOW-UP--Finally, follow-up! First year survival can top 98 percent only to be followed by failure a year or so later. Animals, insects and disease, grass competition, and drouth can spell ruin to otherwise successful first year plantations. The forester that ignores plantation follow-up does so at his own risk. Frequently a plantation can avoid potential ruin if the forester is vigilant and catches the threat in time.

Planning, seed, seedlings, site preparation, planting, and follow-up: each is a key element of a total job. Each element breaks down into the separate tasks that are essential to subsequent steps and critical to over-all plantation success. Each task must be performed properly between plan and plantation.

SUMMARY--I have personally visited many plantations within the last year. Some would sadden, others gladden a foresters' eyes. Consistent plantation success is needed to insure sufficient forest products for meeting future needs. Where reforestation is assigned similar priorities, with corresponding budgets and skills as those now devoted to firefighting, and harvesting, reforestation success should follow. This day is now dawning in response to critical reforestation need.

SPRAY JOB

A Spray-Deposit Assessment Workshop was held at Davis, California, March 16-18, 1976. Out of this grew Technical Bulletin Number 1596 titled: Methods for Sampling and Assessing Deposits of Insecticidal Sprays Over Forests. This 162 page book is both up-to-date and authoritative. It does not tell you how to spray, just how to measure what reaches the ground.

Your copy is available from the USDA Forest Service, Forest Insect and Disease Management, Methods Application Group, 2810 Chiles Road, Davis, CA 95616.

PLUG-1 TRANSPLANTS

Kerwin Doughton, owner of the Tyee Nursery, recently sent me a copy of a paper that Steve Schalla gave at the 19th annual meeting of the International Plant Propagators Society. It describes the growing and using of plug-1 transplants.

The Tyee Nursery grew several million plug-1 transplants for Georgia Pacific, Champion Timberlands, and others. All of these clients reported the following

advantages of the plug-1 over the 2-0 and 2-1:

1. Two rather than 3-year growth cycle.

2. The plug-1 transplant has more consistent height, root system, and caliper than the other types.

3. The fall transplanted plug-1 is a larger tree than the others.

4. Late summer transplants appear more vigorous than the others and recover from browsing more readily.

For details write: Steve Schalla, Tyee Nursery, Box 8 Umpqua, OR 97486 for your copy of this excellent 14 page paper titled: Transplanting the Douglas-fir Plug.

BUGS A PROBLEM?

Black flies, mosquitoes, and deer flies are a real problem in some places. A chap in Maine offers the "oily hat" trick to help solve the problem.

Clayton Totman coats his hard hat with mineral oil, baby or any other available light oil. He finds that the bugs go for the oil instead of his hide.

According to Totman, his system works for most flying insects--another incentive for wearing a hard hat.

CONTROLLED RELEASE HERBICIDES

G. Graham Allen, a University of Washignton Professor, sent me a reprint of a paper titled: Growth Enhancement of a Juvenile Conifer Forest 6 Years After Application of a Controlled Release Herbicide.

This paper traces the growth history of a Douglas-fir plantation 6 years after an initial treatment of a controlled herbicide based on the chemical combination of 2,4-dichlorophenoxybutyric acid (2,4-DB) with Douglas-fir bark. The most effective level tested has increased tree height growth by more than 15 percent and the stem wood volume by 74 percent.

Superior growth was observed as a direct result of application of the controlled released herbicide. This would suggest that the release of the auxin-type herbicide is providing the conifer with a metabolic stimulus in addition to the several benefits accruing from the suppression of competitive vegetation. Request copies from Professor G. G. Allen, College of Forestry Services, University of Washington, Seattle, WA 98195

ROOTS

Few deny the importance of roots, yet few forest scientists study roots intensively. Forest Service Region 9, headquarted in Milwaukee, has been rounding up reports on root research and the results published. Their "rooting habits" project has develed a number of summaries and one such was on cottonwood Populus deltoides Bartr. This report covers the general morphogenesis and morphology, relation to crown, response to moisture conditions, mycorrhizae, and infectious and noninfectious diseases. I wish there were similar summaries for the important western species.

If any of our readers know where similar summaries are available for western species,

please let me know in order to share this important information.

Write Timber Management, Forest Service Region 9, for a sample summary. The address is: Forest Service, USDA, Timber Management, Eastern Region(R-9), 633 West Wisconsin Ave., Milwaukee, WI 53203.

CONTAINER SIZE-ARTIFICIAL LIGHT

Dan Miller, Potlatch Research Forester, described last January how artificial light and container size affect the growth of various conifers.

Based on the growth data generated by his study, he recommends the following growth regimes:

SPECIES	TREATMENT	CONTAINER SIZE
White Pine	Photo period*	4
Douglas-Fir	Photo period* or none	4
Ponderosa Pine	None	8

* 1978 data suggest that the photo period lights are neccessary.

These treatments should produce seedlings of acceptable size given lighting and container costs restraints.

We suggest you write Dan for your copy of the excellent 10 page paper. His address is: Potlatch Corporation, Wood Products, Western Division, P.O. Box 1016, Lewiston, ID 83501. Ask for Forestry Technical Paper, TP 78/4 titled: Lights and Container Size Influence Greenhouse Growth of Conifers.

GENIPONICS

This is the General Electric trade name for their controlled environment system for growing vegetables. The company scientists have been able to produce seven crops of tomatoes a year as compared to two in a greenhouse and one when a farmer works his field. They claim no insecticides or fungicides are needed under the completely controlled environmental system developed.

For details of the system write:

Dr. Eion G. Scott, Technical Director
Controlled Environmental Agriculture Operation
Electronics Systems Division
General Electric Company
Court St. Plant #2
Syracuse, New York 13201

ANIMAL DAMAGE AND VOLUME GROWTH

Phil Hahn, Georgia Pacific's Manager of Forest Research, published a paper titled: The Effect of Animal Damage on Volume Growth. It details the results of a 14-year study of this matter. He found that the latest data taken in 1978 revealed that 77% of the caged trees survived as compared to 57% survival for uncaged trees. The caged trees produce 422 cu. ft./acre volume, while the uncaged trees produced

160 cu. ft./acre volume. The 262 cu. ft./acre volume loss indicates the seriousness of the economic problem due to animal damage.

This is the most precise measurement of long-term animal damage I have seen so far.

Write Phil for your copy. The address is: Georgia Pacific Corp., Box 1618, Eugene, OR 97440.

ISSUE BRIEFING PAPER

We've got a couple of boxes of the USDA Forest Service Issue Briefing Paper #8 in our office. Titled, Use of the Herbicide 2,4,5-T, this five page paper dated 10/27/78 is a well-written, authoritative statement of the background, and use of this chemical. We'll be glad to supply a copy or two as long as our supply lasts.

PRESCRIBED BURNING

John Dell and Bob Martin wrote Planning for Prescribed Burning in the Inland Northwest. They point out that, historically, fire has played a role in forests and ranges of the inland Northwest. Prescribed burning frequently precedes reforestation west of the Cascades.

This publication was prepared to understand the role of fire, its potential use, and how to plan such use in managing these lands. Various sections deal with the topics and steps in planning a prescribed burn are outlined. Examples and references are provided.

Write the PNW Station, Box 3141, Portland, OR 97208 for General Technical Report PNW 76.

HERBICIDE SUMMARY

Dr. "Hank" Gratkowski has a scientific lifetime of herbicide study behind him. Just published is his 12/78 publication titled Herbicides for Shrub and Weed Control in Western Oregon. It describes the herbicides that Hank has tested on 16 common shrubs over the past 24 years. Hank's work is always thorough and well done. Need we say more!

Write the PNW Station, Box 3141, Portland, OR 97208 for General Technical Report PNW-77.

TREE STORAGE

From now through spring, some folks will be having trees stored until they can get on the land to plant them. Many will be placed in refrigeration facilities where other trees are stored. This is good, however, some may be placed in local cold storage plants where fruits and vegetables are kept. Tree seedlings should not be placed in refrigerated storage along with apples. Apples in storage give off ethylene gas and this, I'm told, is bad news for trees seedlings. Check your local extension agent for details. In any event, "a word to the wise is sufficient."

THIRAM

Thiram will be available in 1979. It will be marketed as Therasan 42-S.

Available from the: Hopkins Agricultural Chemical Company, Manufacturing Division Box 7532, Madison, WI 53701. Phone (608) 222-0624.

MYCHORRHIZA

The International Forest Seed Company (IFSCO) now has a method of pelletizing loblolly pine seed and *Pisolithus tinctorius* (P.T.) mychorrhiza spores.

They claim successful P.T. development as the loblolly pine seed germinates and the seedlings develop-a development which has been awaited for some time. IFSCO has an inventory of P.T. and will pelletize your seed or theirs. We need to know whether southern spores will "do their thing" in the Pacific Northwest. Why not try a small amount and let Forestation Notes in on the results.

For information contact W. S. Isaacson or O. R. Sampson at IFSCO. The address is: Box 76008, Birmingham, AL 35223. Phone (205) 591-1989.

COSTS AND PRESENT PRICES

The Washington County (Oregon), Small Woodland Owners Association met Saturday, February 3, to develop their periodic review of reforestation as an investment.

The panel agreed on the current costs and stumpage prices to be used in an economic analysis.

Establishment Costs

Item	Year	Amount/acre
Site Preparation	1	$ 135.00
Plant	1	82.50
Grass Control	1	22.00
Replant and/or spray	2	10.00
Spray	2	11.00
Animal Control	4	10.00
Brush Control	5	5.50
Pre commercial thin	12	50.00
	Total	$ 326.00

ANNUAL COSTS

Taxes	$ 2.82
Fire Control	0.35
Roads	3.30
Liability	1.50
Travel	4.25
Administration	8.00
Total	$20.22

CURRENT RESULTS

AGE	Vol.	Stumpage/MBF	Logging Cost/MBF	Net to owner/MBF
35	3.7	270	162	108
44	6.3	270	125	145
51	4.2	300	100	200
60	27.7	300	100	200

The panel consisted of loggers and woodland owners. They are intimately acquainted with current costs and returns.

Many of our readers have found the data used in these periodic reviews useful.

ENERGY CONSERVATION

Steve McDonald is taking a semester off to catch up on his chores. Under the above heading he sent a number of useful pamphlets:

Energy Conservation and Solar Heating for Greenhouses points out that one must consider all trade-offs before making changes. After all, greenhouses are designed to produce high yielding crops. Efforts to save energy which limit production can be "counter productive." This pamphlet urges careful analysis.

Another publication along the same lines is: Energy Conservation in Greenhouses. This attempts to bring together much of the widely-scattered information previously available only in trade journals, extension publications, and technical research reports. This publication covers heat reduction, heat saving, and the use of solar energy as a heat source.

A five-page review from the February 1977 Horticulture Industry provides articles titled: "Thermal Screens, Some Technical and Economic Aspects," " Calculating the Cost of Saving Fuel With Screens," "Half Your Heat Loss," and "Old or New Houses Can Justify Thermal Screens." Judging from the advertisements, this is apparently a Canadian publication.

Energy Saving in Greenhouses outlines the theory and practice of fuel saving using inflated roof construciton and the use of thermal screens at night. This article is from the Instrumentation Division, National Institute of Agricultural Engineers in Silsoe, Bedfordshire, Great Britain. The authors are B. J. Bailey, et al.

This appeared in pages 501-508 in Physics in Industry, edited by E. Omongain & C. P. O'Toole. 1976 595pp.

Reducing Heat Losses in Polyethylene Covered Greenhouses was published as American Society of Agricultural Engineering (ASAE) paper No. 75-4022 in March 1976.

The paper reports environmental and outdoor tests of using curtains to prevent heat loss. Such curtains provided savings "of 1 to 43 percent of the total heat requirement of the prototype greenhouse." The authors found it more effective to fasten the curtain from eave to eave under the roof rather than from eave to peak.

Check your scientific Library for copies of this paper or send to Steve McDonald, Nursery Specialist, Forest Service, 11177 W. 8th Avenue, Box 25127, Lakewood, CO 80225 for this and the five other papers cited.

NEW HANDBOOK

"Pete" Passof says California has gotten it together" for a small woodland owner. The California Forestry Handbook written by T. F. Arvola is a practical forestry guide and a bargain at $2.50 a copy. Send money orders or checks payable to State of California, Office of Procurement Publications Sections, Box 1015, N. Highlands, CA 95660.

INCREASED ROOT GROWTH

The root growth of containerized seedlings grown in the Northwest needed improvement. Barbara Thompson, OSU forest science researcher, found that root growth during the dormant period (January - April) can be increased: 1) by increasing the photoperiod, 2) maintaining a temperature between 15 - 20° C, and 3) selecting a superior soil medium. Results show that different species may have different soil requirements for optimum growth.

Photoperiod and air temperature have pronounced effects on root growth. Thompson found that a slight modificaiton of the greenhouse cultural regime can result in larger root systems by spring planting time without greatly affecting the time of bud break.

For details write: OSU Forest Research Laboratory, Corvallis, OR 97331

SEEDLINGS AVAILABLE

Fred Hensel called to say he has a half-million plug seedlings available. These are from Oregon seed sources. Anyone needing seedlings for immediate use or for later use as plug-ones should get in touch with: Fred Hensel, Louisianna Pacific, Big Lagoon Operation, Trinidad, CA 95570. Phone: (707) 488-2531 or 2411.

APPENDIX A
ERRATA - METEOROLOGY

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p 70, L 35: s.r. "not considered. The model is adiabatic and hydrostatic."

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p 71, L 21: s.r. "insofar as it utilizes quite a number of empirical relations"

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L 24 : s.r. "California. A sequence of corrections is made to the magnitude and direction of a uniform geostrophic wind imposed"

p 72, L 12: s.r. "slope with slope cooling, i.e., it is not adiabatic but"

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p 72, L 31: s.r. "Geographic coordinates are used so that curvature is"

p 73, L 25: s.r. "estimates based on empirical fits of five constants,"

p 74, L 4
L 5 : s.r. "Ball, K. Winds on the ice slopes of Antarctica. Intl. Symp. of Antarctic Meteor. Melbourne, 1959. Pergamon"

p 75, L 6 : s.r. "intensity, or equivalently an entrainment coefficient."

p 75, eq(4): s.r.

$$\left(\frac{\text{windspeed}}{\text{friction velocity}}\right) = \text{log function of } \left(\frac{\text{displaced height}}{\text{roughness length}}\right) + (\text{stability factor}) \times (\text{displaced height})$$

p 75, L 24
L 25: s.r. "The friction velocity is the square root of the ratio of the surface drag force (i.e., the tangential
L 26 turbulent stress) to the air density."

p 77, L 6
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L 8 are available in the literature for"

p 77, L 32: s.r. "roughness length; but there is little agreement on the"

p 79, L 7 : s.r. "some doubts as to their significance; but if these local"

p 79, L 19: s.r. "vertical wind profile or the diffusivity to be predicted"

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p 11, RHS, L 27: s.r. "appropriate to tests of SF model or"

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